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A METHODOLOGY FOR MAKING A QUANTITATIVE ASSESSMENT OF PASSENGER--ETC(U)
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Final Report

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Prepared for:

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
OFFICE OF NAVAL RESEARCH
ALEXANDRIA, VIRGINIA 22332

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U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
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Final Report *April 4, 1977*

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ABSTRACT

This report presents methodologies for assessing alternative passenger transportation schemes quantitatively on the basis of criteria related to energy conservation, air quality, commuter costs, and land use. The purpose of the research has been to demonstrate the feasibility of applying quantitative assessment procedures for evaluating transportation options, with the results to serve as a blueprint for possibly more general application in other communities using similar criteria under similar conditions.

Two basic approaches to assessment are addressed. A manual procedure produces estimates of fuel consumption, pollutant emission (carbon monoxide and hydrocarbons), and carbon monoxide concentration, commute costs, and land use for each link of a road network used by commuters. Per-vehicle factors, developed from a one-time baseline analysis, enable alternative commute options to be assessed on a relative basis in terms of change in passenger car volume on the commute network. Input to the procedure consists of road network physical and operational traffic characteristics during the peak commute hours of the baseline year, traffic volume changes associated with various alternatives, meteorological conditions likely to result in higher-than-average pollutant concentrations and per-person costs for each mode of travel and existing land-use characteristics.

As an alternative approach to the manual assessment process, a computerized version is also developed. The report concludes that the principle advantages in computerization are the ability to handle more complex and repetitive analysis problems and the avoidance of errors in algorithmic calculations.

The manual and computerized methods were tested on a number of hypothetical but plausible scenarios in the Tidewater, Virginia, area and the results are presented as a demonstration of the usefulness of the methodologies.

SYMBOLS

C	Approach capacity (vehicles per hour); the actual number of vehicles able to pass through an intersection during a 1-hour period under intersection control.
C_f	Free-flow capacity (vehicles per hour); the maximum number of vehicles physically able to traverse the narrowest part of a link in the absence of interruption.
(C_f-V)	Cross-stream tolerance (vehicles per hour); the difference between free-flow capacity and demand volume in the traffic stream to be crossed or entered by vehicles after stopping at a signed intersection.
C_g	Toll gate capacity (vehicles per gate per hour); the maximum number of vehicles able to pass through the gate in the course of 1 hour, under normal operating conditions.
C_y	Cycle length (seconds); the time required for a traffic signal to progress through all its phases.
D	Delay (seconds); the total excess time spent on a link due to intersection control in undercapacity conditions, with an assumed maximum delay equal to signal cycle length in the case of signalized intersections.
$D+$	Additional delay (seconds) at overcapacity signalized intersection approaches.
G	Green time (seconds); the amount of time during a 1-hour period that vehicles on a controlled link segment experience a green signal.
H	Toll gate headway (seconds); the average time interval between vehicles leaving the gate.
L	Number of lanes comprising an intersection approach segment.
N	Stopping rate (vehicles per hour); the number of vehicles on a given link which are required to stop by control at an intersection during a 1-hour period.
N_q	The number of vehicles in a queue.
P	Proportion of stops; the ratio of stopping vehicles to demand volume.

S Saturation volume (vehicles per hour); the maximum number of vehicles physically capable of passing through an intersection during a 1-hour period, on a single link approach segment, assuming no interruption of flow.

T Truck factor; an adjustment for the presence of heavy-duty vehicles in the stream.

V Demand volume (vehicles per hour); the actual number of vehicles using a link during a 1-hour period.

W_a Approach width (feet); the width of a given intersection approach segment.

X_q Queue length (meters); the length of the line of vehicles forming on an intersection approach while waiting at a signal or sign.

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ACKNOWLEDGMENTS

The SRI project team would like to express its appreciation to those persons in the study area of Norfolk, Virginia, who so freely gave of their time to assist in the research effort. We would particularly like to thank Mr. Pat Tedesco, Mr. Bob Warren, and Mr. Charles Carrington of the Naval Facilities Engineering Command Planning Office for their assistance in providing data.

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Our thanks also go to Mr. Joseph W. Crawford, Jr., Assistant Regional Director (Engineering) of the State Air Pollution Control Board, Commonwealth of Virginia, for his assistance in obtaining air quality and meteorological information for use in the project analyses.

Finally, we would like to acknowledge the supportive input from the two contract officers for the project: Mr. Jerome Hinkle, Division of Transportation and Energy Conservation, ERDA, and Mr. Stephen M. Hurley, Environmental Protection Program, Naval Facilities Engineering Command.

INTRODUCTION

An important test of any program, development, or production is the ability to evaluate it objectively against an established set of standards. Policy-relevant criteria and quantitative analysis are the basis for exercising such judgments. To date, evaluation of the Navy passenger transportation program has been made primarily by an implicit set of standards. To enable continued development of the program and to evaluate its effectiveness, an explicit set of standards and a method for evaluation need to be established. The purpose of this project has been to develop an appropriate evaluation methodology and demonstrate it in a selected military community.

Background

The current project is the third in a series of Navy transportation RDT&E efforts beginning with "An Assessment of the Relevance of Transportation Research to Naval R&D" (December 1974), and followed by the ongoing study "The Development of a Transportation Demonstration Project To Be Implemented in a Military Community" (Contract No. N00014-75-C-05068).

The initial Navy transportation project was tasked to document the problem statement and criteria for Navy involvement in a cooperative passenger transportation program from the perspective of Navy environmental protection, energy conservation, and installation planning programs. The results of the initial research clearly indicated that there are potential benefits for the Navy in a transportation program, such as reduced parking requirements, reduced base traffic congestion, and improved community relations. Thus, a second project was initiated to carry the research concept one step farther by demonstrating how the Navy--in the selected pilot area of Tidewater, Virginia--might establish a cooperative transportation program with the adjoining communities and with other federal agencies capable of funding transportation proposals. As part of the ongoing research effort, a process has been established in the Tidewater area for carrying out cooperative transportation planning. A joint Navy/community advisory committee was established to work out the objectives of a cooperative program, and to begin formulating the institutional arrangements to carry out necessary actions. A 5-year transportation action plan has been outlined as a tool for guiding transportation development in the Tidewater area, and several of the recommended actions have been initiated. For example, a $490,000 grant was awarded by the DoT-Urban Mass Transportation Administration to the Tidewater Transportation District Commission in December 1976 to purchase fifty 12-passenger vans specifically for leasing to Navy commuters. Additionally, the publicly operated bus company has extended its system to include a regular on-base service at Sewells Point (the most populous base in Norfolk).

During the development of the transportation action program, preliminary criteria were established by the project team and advisory committee for evaluating transportation-related recommendations (see Table 1). Though the criteria were referred to while developing transportation actions and used in modifying the final action plan, actual quantitative measurement techniques were not employed at that time. Since the initial phase of the program was oriented toward establishing the cooperative transportation process, it was felt that analytical techniques would be better applied once the pilot program was under way. This approach has proved successful in Tidewater. However, it is now desirable to provide a more objective basis for evaluating the transportation program in general, along with the effectiveness of its component parts.

Table 1

PRELIMINARY TRANSPORTATION ACTION CRITERIA

Areas of Concern	Evaluation Criteria
Air pollution	Reduced emissions (tons of pollutants) from autos
Energy consumption	Gallons of fuel consumed
Noise	Traffic noise
Land use	Reduced need for land area used for parking (improved flexibility due to increased land available for alternative uses)
Amenities	Improved design composition of Navy property
Transportation cost (to Navy, travelers, community)	Operating and capital cost
Accidents	Reduced fatalities, injuries, property damage
Safety/vandalism	Crime reduction in parking areas
Travel time	Hours of travel time reduced for Navy commuters
Travel comfort	Traffic congestion and stress reduced
Convenience of travel	Number of travel alternatives available to Navy commuters improved
Service to persons of limited mobility (handicapped, poor, elderly, and so on)	Number of persons not previously served

Benefits of Developing Measurement Techniques

A number of benefits from the application of objective measurement techniques can be identified, some of which follow:

(1) A quantitative assessment of the effectiveness of each action in the Navy areawide transportation action program, as measured by evaluation criteria, will point out benefit/cost ratios to the Navy and the community, thus providing valuable input for prioritizing actions in the decision-making process, and could provide the necessary momentum for implementing portions of the plan. For example, though the initial community investment for improved bus service to naval installations in Tidewater is high, the long-term benefits (e.g., reduced need for roadway expansion; less traffic congestion, thus fewer traffic controls; reduced accidents) may justify the short-term expenditure.

(2) The ability to point out the merits of the pilot program in a quantitative format will help arouse the interest of Engineering Field Divisions in initiating similar programs at other naval installations in the United States.

(3) An objective evaluation of the relationship between the Navy transportation program and established Navy standards and goals (e.g., energy conservation--such as OPNAV Instruction 4100.5; environmental protection--reduced emissions and noise levels; improved land use) will make periodic installation- and Navy-wide monitoring and accounting possible. For example, statements such as the following would be possible: "The Navy, through its transportation program, reduced parking space requirements at five major installations, saving over 500 acres of prime government property." "Over 40,000 Navy employees carpooled this year, saving an estimated 10,000,000 gallons of gasoline."

(4) The final, and most wide-reaching advantage of objective measurement of the Navy transportation program is the availability of an ongoing structured example to prove or disprove the premise that changes in transportation patterns can effectively influence land use, energy consumption, and environmental quality within a region. The established data base and the easy access to further data as transportation actions are implemented or stimulated offer a unique source of information to R&D programs for other agencies grappling with these questions, primarily ERDA, FEA, EPA, and DoT.

To demonstrate quantitative evaluation of action plans, we have selected four of the action criteria from Table 1--air pollution, energy consumption, land use, and transportation cost--and developed approaches

for a step-by-step quantified evaluation in terms of the selected criteria. The procedure for applying these methods is then demonstrated in the Tidewater, Virginia, area for a hypothetical but plausible set of passenger transportation options.

METHODOLOGY

General Approach

The automobile has proved a convenient mode of transportation for most commuters. This convenience, however, exacts a great price in terms of energy (fuel) consumption, air quality degradation (pollution), and amount of land committed to accommodating the private automobile. In an urban region, for example, the adverse energy and air quality impacts of individual auto use far outstrip such impacts for other modes of transportation. Because of the overriding impact of the automobile in this regard and the concentration of traffic volumes in the commute hours, many communities are seeking alternatives to traditional commuter transportation patterns. In choosing among candidate options, relative effectiveness in mitigating negative side effects like fuel consumption and air pollution problems must be assessed. In the interest of such an assessment, we have developed a methodology for quantitative comparison of selected impacts of alternatives. The methodology consists of defining a suitable network of commuter routes and computing the differences in fuel consumption, air pollution, transportation-user costs, and land use associated with the candidate transportation options. The results can then be used, along with the other decision criteria cited in Table 1, for deciding the relative merits of the transportation options that are feasible for the commute corridors being analyzed.

Network Description

Specification

The first step in the methodology is to define the network or commute corridors to be analyzed. By general definition, a network will consist of all the major roadways used by commuters in traveling between a point of origin and a point of destination. For the purpose of analysis, the network is divided into elements consisting of points of roadway intersection and roadway segments (links) connecting the intersection points. Figure 1 illustrates a network in the Tidewater, Virginia, region. Depending on the scope and purpose of the analysis, a network may be chosen that is more or less detailed than that shown in Figure 1. For each road segment connecting intersection points, a one-way link must be designated separately for each direction of traffic flow (except, of course, in the case of one-way roads). Entry and exit ramps to limited-access roads may be treated as separate links if such detail is desired.

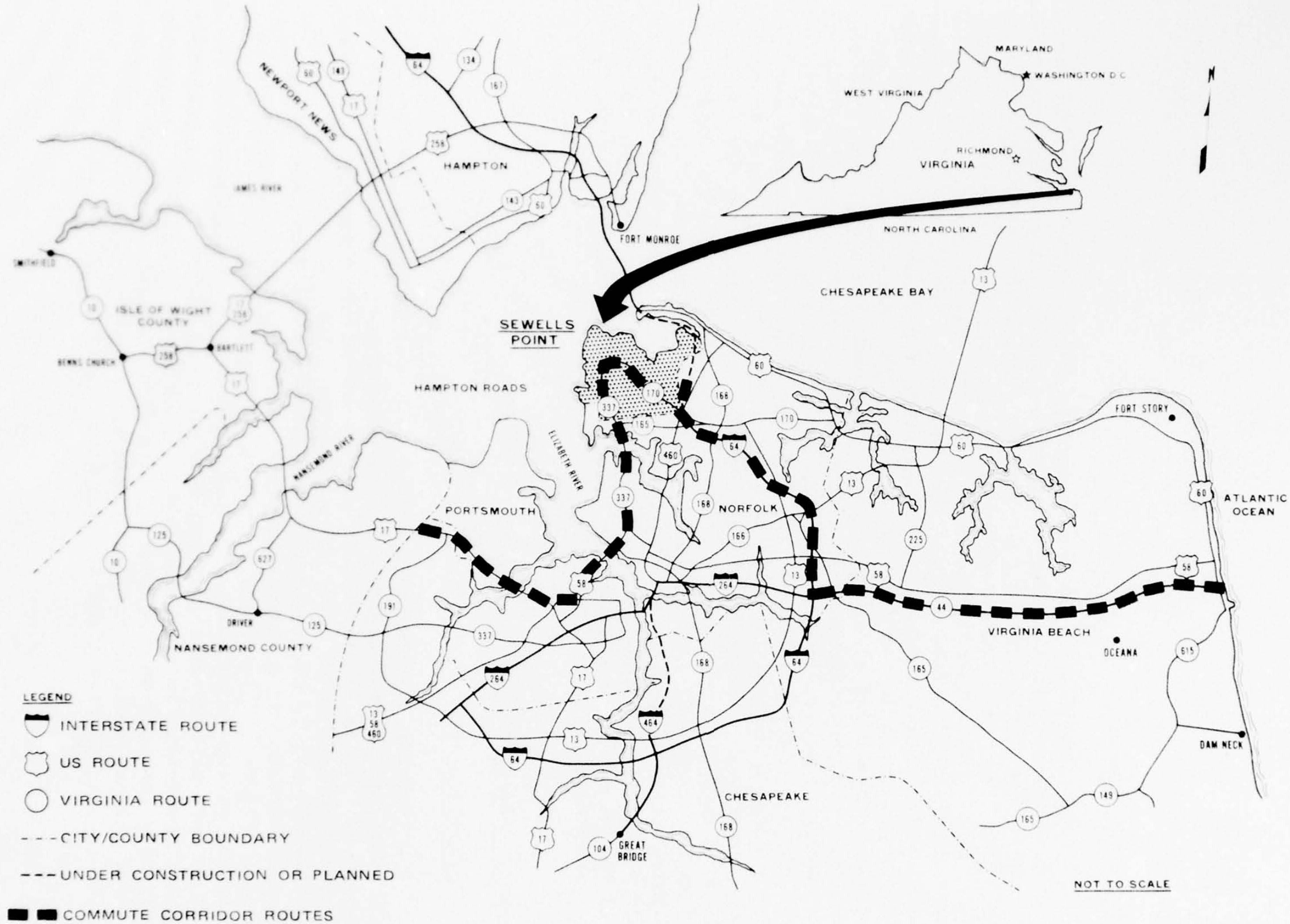

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FIGURE 1 COMMUTE CORRIDOR ROUTES TO SEWELLS POINT IN THE TIDEWATER AREA

Configuration

Before beginning the analysis, the regional configuration of the chosen network is determined. Desired routes must be chosen and appropriate intersections must be designated. Appropriate intersections are those points along the commute route at which commute traffic is controlled by signals or signs. A schematic network map is then drawn to scale, as illustrated in Figure 2, using straight lines to approximate the network geometry. Links and intersection points should be numbered for ready reference and coordinates assigned to the intersection points for use in automated analysis. Figure 2 is a schematic representation of two commute corridor routes (heavy dashed lines in Figure 1) chosen for demonstration of the methodology on Sewells Point commute options. Links and intersections are identified by code number in Table 2.

Physical Characteristics

Each road link possesses certain physical characteristics that must be known or assumed as input to the impact assessment process. In all, six such characteristics must be determined as indicated and defined below:

- Link length:* The distance (in miles) along a link between intersection or direction-change points. It will normally be sufficient to determine distance to the nearest one-tenth mile from a properly scaled regional network map.

- Number of lanes: The predominant number of (through) lanes comprising the link, excluding turning channels and acceleration-deceleration lanes.

- Lane width: The average width (in feet) of the lanes that comprise the link.

- Approach width: The shoulder-to-shoulder or curb-to-curb width (in feet) of the link at the downstream (forward) intersection approach. Depending on the detail required of the analysis, the intersection approach may be divided into sepearate elements consisting of through lanes and specially designated turn-only channels. Separate widths can be calculated for each element and element-specific analyses can be performed.

- Parking facilities and bus stops: The presence or absence of facilities for curbside parking on an intersection approach within 250 feet of the intersection, and the presence

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*Double underlining indicates primary inputs to fuel consumption and air quality assessments.

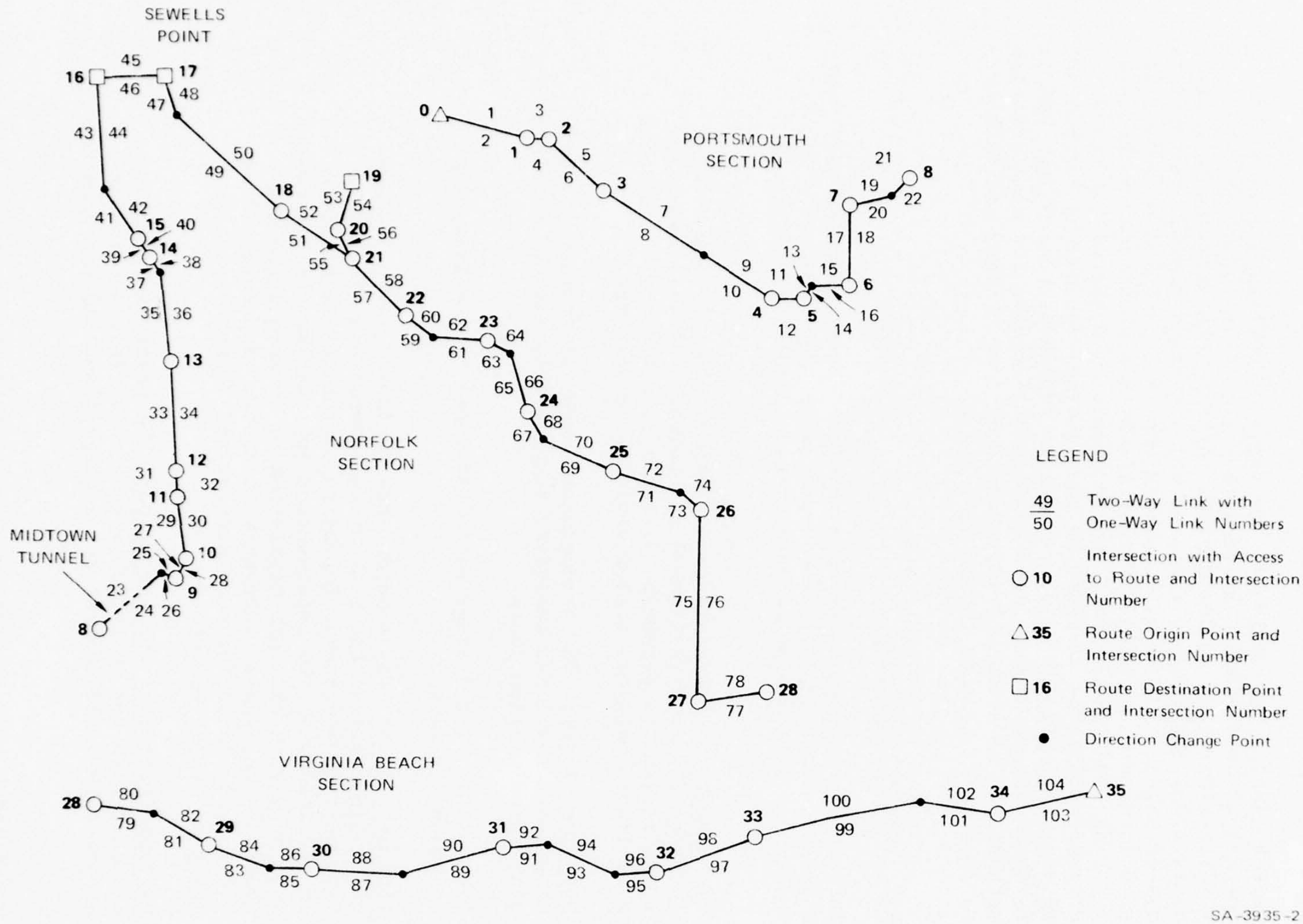

FIGURE 2 SCHEMATIC REPRESENTATION OF CORRIDOR ROUTE LINK-INTERSECTION NETWORK

Table 2

IDENTIFICATION OF LINKS, INTERSECTIONS, AND DIRECTION CHANGE POINTS

Link* Number	City Location	Link Streets and Cross-Streets†	Downstream† Intersections
1-2	Portsmouth	High Street between (Collins Blvd.) and Tyre Neck Rd.	0 - 1
3-4		High Street between Tyre Neck Rd. and Stamford Rd.	1 - 2
5-6		High Street between Stamford Rd. and Cedar Lane	2 - 3
7-8		High Street between Cedar Lane and (Riverside Dr.)	3 - X
9-10		High Street between (Riverside Dr.) and Frederick Blvd.	X - 4
11-12		High Street between Frederick Blvd. and Air Line Blvd.	4 - 5
13-14		London Blvd. between High Street and (Glasgow St.)	5 - X
15-16		London Blvd. between (Glasgow St.) and Harbor Blvd.	X - 6
17-18		Harbor Blvd. between London Blvd. and Wesley St.	6 - 7
19-20		Harbor Blvd. between Wesley St. and (Carolina Ave.)	7 - X
21-22		Harbor Blvd. between (Carolina Ave.) and toll plaza	X - 8
23-24	Norfolk	Midtown tunnel between toll plaza and (Raleigh Ave.)	8 - X
25-26		Midtown tunnel between (Raleigh Ave.) and Hampton Blvd.	X - 9
27-28		Hampton Blvd. between Brambleton Ave. and Princess Anne Rd.	9 - 10
29-30		Hampton Blvd. between Princess Anne Rd. and 27th St.	10 - 11
31-32		Hampton Blvd. between 27th St. and 38th St.	11 - 12
33-34		Hampton Blvd. between 38th St. and Jamestown Crescent	12 - 13
35-36		Hampton Blvd. between Jamestown Crescent and (Shore Rd.)	13 - X
37-38		Hampton Blvd. between (Shore Rd.) and Little Creek Rd.	X - 14
39-40		Hampton Blvd. between Little Creek Rd. and Airline Terminal Blvd.	14 - 15

Table 2 (Continued)

Link* Number	City Location	Link Streets and Cross-Streets†	Downstream‡ Intersections
41-42	Norfolk	Hampton Blvd. between Airline Terminal Blvd. and (Allen St.)	15 - X
43-44		Hampton Blvd. between (Allen St.) and Adm. Tausig Blvd.	X - 16
45-46		Adm. Tausig Blvd. between Hampton Blvd. and Bainbridge Ave.	16 - 17
47-48		Adm. Tausig Blvd. between Bainbridge and (main runway)	X - 17
49-50		I-564 between (main runway) and Airline Terminal Blvd.	18 - X
51-52		I-564 between Airline Terminal Blvd. and Little Creek Rd.	21 - 18
53-54		Granby Ave. between I-64 and Gate 22	20 - 19
55-56		I-64 between Granby Ave. and Little Creek Rd.	21 - 20
57-58		I-64 between Little Creek Rd. and Tidewater Dr.	22 - 21
59-60		I-64 between Tidewater Dr. and (Lasser Dr.)	X - 22
61-62		I-64 between (Lasser Dr.) and Chesapeake Blvd.	23 - X
63-64		I-64 between Chesapeake Blvd. and (Byrdley Ave.)	X - 23
65-66		I-64 between (Byrdley Ave.) and Norview Ave.	24 - X
67-68		I-64 between Norview Ave. and (Texas Ave.)	X - 24
69-70		I-64 between (Texas Ave.) and Military Highway	25 - X
71-72		I-64 between Military Highway and (Roderfield Ave.)	X - 25
73-74		I-64 between (Roderfield Ave.) and Princess Anne Rd.	26 - X
75-76		I-64 between Princess Anne Rd. and V-44	27 - 26
77-78		V-44 between I-64 and Newtown Road	28 - 27
79-80	Virginia Beach	V-44 between Newtown Rd. and (Toy Ave.)	X - 28
81-82		V-44 between (Toy Ave.) and Witchduck Rd.	29 - X
83-84		V-44 between Witchduck Rd. and (Judi Court)	X - 29

Table 2 (Concluded)

Link* Number	City Location	Link Streets and Cross-Streets†	Downstream‡ Intersections
85-76	Virginia Beach	V-44 between (Judi Court) and Independence Blve.	30 - X
87-88		V-44 between Independence Blvd. and (Thames Dr.)	X - 30
89-90		V-44 between (Thames Dr.) and Rosemont Rd.	31 - X
91-92		V-44 between Rosemont Rd. and (N. Plaza Rd.)	X - 31
93-94		V-44 between (N. Plaza Rd.) and (Gimbart St.)	X - X
95-96		V-44 between (Gimbart St.) and Lynnhaven Rd.	32 - X
97-98		V-44 between Lynnhaven Rd. and Great Neck Rd.	33 - 32
99-100		V-44 between Great Neck Rd. and (Oceana Blvd.)	X - 33
101-102		V-44 between (Oceana Blvd.) and Birdneck Rd.	34 - X
103-104		V-44 between Birdneck Rd. and Atlantic Ave.	35 - 34

*Link numbers refer to Figure 2. Odd-numbered links are outbound from Sewells Point; even-numbered links are inbound.

†Street names or locations in parentheses are direction change points and not intersections.

‡Intersection numbers in circles refer to Figure 2 and represent the downstream intersections for the link in question. An "X" indicates a downstream direction change point.

or absence of a bus stop on the near or far side of the intersection should be noted.

- Metropolitan population: The population of the city or metropolitan area in which the network is located must be determined.

Figure 3 illustrates the physical characteristics of roadway links.

Operational Characteristics

In addition to the physical characteristics described above, each link will possess operational characteristics that must also be known or assumed as input to the assessment process. In all, 11 such characteristics must be determined as indicated and defined below:

- Demand volume: The number of vehicles passing any given point on the link in the course of an hour. Demand volume will vary with the hour of the day.

- Operating speed: The highest speed in miles per hour attainable on the link consistent with the operational and physical characteristics of the link.

- Proportion of heavy-duty vehicles: Percentage of demand volume that consists of buses and heavy-duty trucks (three or more axles).

- Proportion of turning vehicles: The percentage of vehicles that turn left or right at the downstream intersection. The proportion of turns is computed separately for each approach element (through or turn only). Exclusive through or turn lanes will have a zero proportion of turns associated with them.

- Saturation service volume: The maximum number of vehicles theoretically able to pass through an uncontrolled intersection during an hour, consistent with the physical characteristics of the approach and assuming a maximum traffic load.

- Capacity: The maximum number of vehicles actually able to pass through an intersection consistent with physical and operational characteristics and degree of control, and assuming a maximum traffic load.

- Type of control: The type of control (traffic signal, stop or yield sign, toll booth or gate, or other) to which link traffic is subject at the downstream intersection must be determined. In connection with signalized controllers, the following information must be obtained:

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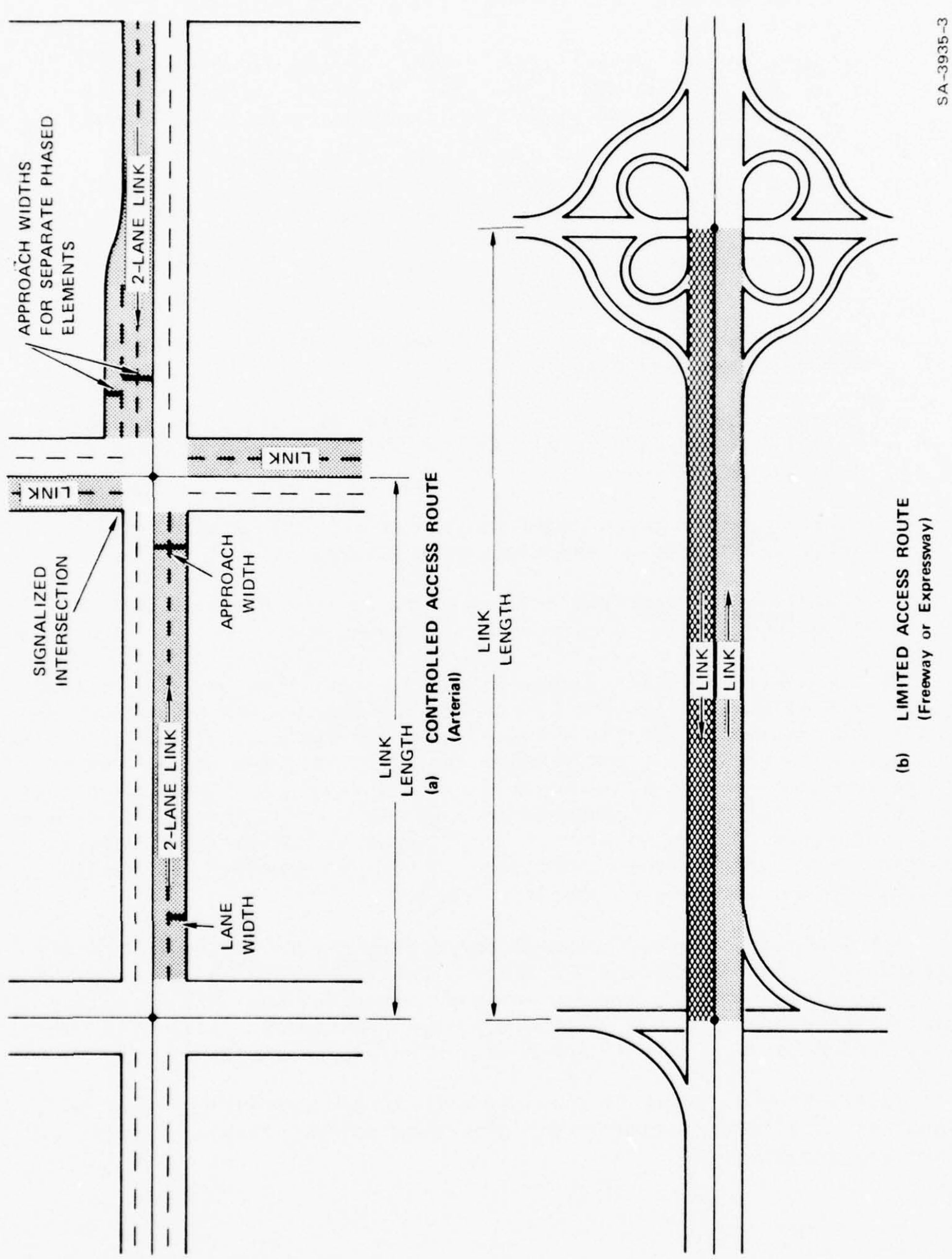

FIGURE 3 PHYSICAL CHARACTERISTICS OF PRINCIPAL COMMUTE ROUTE TYPES

- Signal type: The generic type (fixed, fully or semi-actuated, progressive, computerized, etc.) of any traffic signal.
- Cycle length: The length of time for the traffic signal to pass through all its separate phases.* In the case of a vehicle-actuated signal, the maximum cycle length should be determined.
- Green time: The length of time during each signal cycle when a controlled approach element experiences a green signal. In the case of a vehicle-actuated signal, the minimum green time should be determined. A separate green time is associated with each signal phase.

• Stops: The number of vehicles that stop at the downstream intersection during an hour.

• Delay: The time (in seconds) spent on the link by an average vehicle in excess of the time that would be spent without intersection control.

• Queue length: The average length (in meters) of the line of vehicles stopped at the downstream intersection.

• Vehicle miles traveled: The product of demand volume and link length must be determined for each link.

Of the characteristics described above, those that are not primary inputs to fuel consumption and air quality assessment are secondary input used in the derivation of the primary input information. For clarity, we have chosen to treat only the primary inputs in the body of the report, relegating treatment of secondary inputs to Appendix A. The analyst has the choice of using the worksheets in Appendix A or obtaining the primary inputs directly from an outside source. Experienced traffic analysts familiar with local network conditions should be consulted, if possible, to optimize the accuracy of the input data.

Operational characteristics obtained either directly or indirectly should apply to a single hour of the day which we shall call a study hour. One or more such study hours may be chosen to cover the periods during which given transportation options will be operational. This will normally be one or more of the peak hours, morning and evening.

Information on physical and operational characteristics of network links can usually be obtained from municipal public works or traffic engineering departments.

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*Phase is that portion of a signal cycle that controls a specific traffic movement, such as through, left turn only, through and left.

Manual Screening--Baseline Calculation

To properly assess the impacts of various transportation options, a baseline analysis must be performed. The purpose of the baseline analysis is twofold. First, it is necessary to indicate the existing trends, or no-option situation, against which to measure option effectiveness. Second, it provides a one-time determination of per-vehicle impact, which can be used as the basis for rapid screening of a variety of options. The procedure for the baseline analysis is described as follows and outlined schematically in Figure 4.

Step 1: Assembly of Input Data--For direct use in the impact assessment, the primary input data for each link should be assembled for the study hour in a format similar to that of Data Sheet 1 (data sheets begin on page 23). Worksheets for deriving primary input data are presented in Appendix A. Links should be identified by number as a cross-reference to the network schematic. A separate baseline analysis must be performed for each target year in which transportation options are to be tested on the networks.

Step 2: Calculation of Fuel Consumption--The rate of fuel consumption varies with the mode in which a vehicle operates. The principal modes are acceleration, deceleration, cruise and idle. Fuel consumption also depends on physical characteristics of the road, such as grade and curvature. Techniques for quantitatively assessing vehicle running costs, including fuel consumption, have been developed in References 1 and 2. On the basis of these techniques and ongoing research at SRI, we have constructed Figure 5 (page 28) and Data Sheet 2, which enable determination of hourly fuel consumption on each network link as a function of the primary input information listed on Data Sheet 1. Effects of grade and curvature have been assumed negligible for the typical commute corridor. Fuel consumption estimates for the baseline situation should be made for each link by filling out Data Sheet 2 in accordance with the accompanying instructions.

Step 3: Calculation of Air Quality Impact--Unlike fuel consumption, which has significance primarily in terms of a cumulative value for the network, air pollution effects must be considered on both a regional (networkwide) and a local (site-specific) basis. Regional analysis in terms of total amount of pollutant emitted over the network is useful in assessing the impact of passenger transportation options relative to other regional air quality improvement programs. Local analysis is important, particularly in the case of carbon monoxide, because the greatest impacts on people occur not as a regional total, but rather as a localized impact in the immediate vicinity of congested road links and intersection approaches. Separate procedures are employed for regional and local analysis.

- Regional Impacts--When transportation actions are being considered, a question is often raised as to the extent to which the action will change the regional burden of air pollutants. Such a question can be answered indirectly in terms of changes in trips or vehicle miles traveled, or directly in terms of the

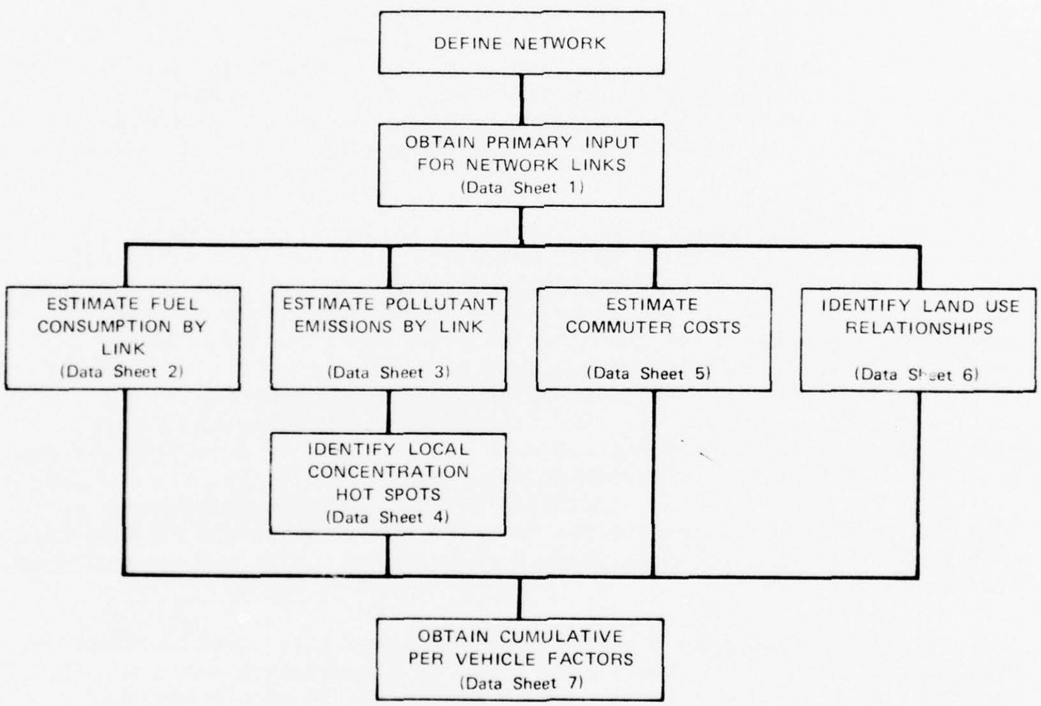

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FIGURE 4 FLOW CHART FOR BASELINE ANALYSIS

change in total amount of pollutant emitted networkwide. Two pollutants are usually of prime interest in relation to auto use because of the large proportion of their regional burden attributable to auto emissions. The first of these, carbon monoxide, is attributable almost exclusively to the auto and has a direct effect on the health of sensitive individuals. The second, hydrocarbon, is somewhat less specific to the auto and is not directly related to health effects, but is a prime constituent in the photochemical processes leading to the formation of health-affecting pollutants known as oxidants. National standards have been set for concentrations of carbon monoxide and oxidant in the ambient air.

The rate of pollutant emission varies with driving mode in a manner similar to that of fuel consumption. Techniques for assessing pollutant emissions by driving mode have been developed in Reference 3. On the basis of these techniques, we have constructed Figures 6 and 7 (pages 31 and 32) and Data Sheet 3, which enable determination of carbon monoxide and hydrocarbon emissions per hour, on each network link as a function of the primary input information listed on Data Sheet 1. Pollutant emission estimates for the baseline situation should be made for each link by filling out Data Sheet 3 in accordance with accompanying instructions.

- Local Impacts. The local impact of transportation options is assessed not in terms of total pollutant emitted over the network, but rather in terms of pollutant concentrations in the air along road links and near intersection approaches. Since carbon monoxide is the auto-related pollutant with the greatest direct health impact, it can be used as a suitable index pollutant for assessing the local, as opposed to regional, impacts of network passenger transportation. Techniques for estimating carbon monoxide concentration near road links and intersections have been developed in References 4 through 7. We feel that a detailed analysis of local impact is best done in an automated (computerized) manner using the method we will describe later in this report. As a screening technique, however, a convenient measure of local impact can be obtained by filling out Data Sheet 4 in accordance with the accompanying instructions. The technique consists of estimating carbon monoxide concentration at roadside, 10 meters from the centerline of a given link, under adverse meteorological conditions expected to result in higher-than-average concentrations. Such roadside values can easily be obtained manually using Data Sheet 4, and can serve as a local air quality measure for comparison of transportation option effectiveness. Appendix D provides additional guidance for estimating local air quality impact.

Step 4: Adjustment in Future Years--Figure 5 (page 28) and Figures 6 and 7 (pages 31 and 32) for fuel consumption and air quality estimation are based on vehicle characteristics valid in 1975. Baseline estimates

for future years will require an adjustment to the results obtained from use of these figures. We are not aware of any satisfactory method for projecting fuel economy into the future and recommend that the values be used unadjusted for future baseline analysis. In the case of air pollution future adjustment is feasible based on mandated emission controls for future model years. Factors for adjustment of air pollution values for future baseline analysis can be obtained from Table 3.

Table 3

ADJUSTMENT OF POLLUTANT EMISSIONS TO FUTURE YEARS

	Model Year Correction Factors* (Base Year 1975) for Link Pollutant Emissions			
Year	Low Altitude Non-California	High Altitude Non-California	Low Altitude, California	High Altitude, California
1975	1.00	1.75	0.99	1.75
1976	0.87	1.55	0.86	1.54
1977	0.76	1.36	0.73	1.33
1978	0.63	1.15	0.61	1.11
1979	0.53	0.96	0.50	0.91
1980	0.42	0.76	0.40	0.73
1985	0.15	0.23	0.33	0.20
1990	0.07	0.07	0.07	0.07

*These correction factors reflect the imposition of interim federal emission standards (for the low-altitude and high-altitude areas) through model year 1977 and the statutory standard thereafter. For California, the correction factors reflect the California interim standards through the 1977 model year and the statutory standards thereafter.

Step 5: Calculation of Commuter Costs--The out-of-the pocket costs associated with commute travel are only a part of the total costs of transportation options. They are important in that they serve to provide excellent quantitative material for marketing programs designed to encourage ride-sharing. One method of presenting automobile costs is to identify the marginal costs to commute by private automobile, which include only the out-of-pocket expenditures for fuel, oil, tolls, parking and allowances for tires, maintenance, and repairs. Marginal costs take into account that a large number of commuters already own an automobile, whether or not it serves as their primary commute mode, so that costs for insurance license, taxes, and depreciation are not included in their cost of

travel to work. Total auto costs are more appropriate if the family operates an extra car for commuting (over 32% of Americans owned more than one car in 1974). Costs for vanpoolers include per-mile ridership costs derived from existing vanpool situations throughout the country. Per-mile costs for vans include all costs because the van is leased specifically for commute travel. Marginal costs are charged for personal use of vans by the driver on weekends and evenings. In this study, auto and van costs are both calculated by passenger-miles traveled and summarized on an annual basis. Bus costs are based on established fares for each zone of travel.

The data requirements and calculations for figuring commuter costs for each mode of travel are identified in Data Sheet 5.

Other costs, not included in this analysis but important to transportation planners for evaluating various modes of travel, are the capital and operating costs associated with alternative transportation options. These are particularly important when assessing new systems (such as installing new equipment, adding new bus lines, or undertaking marketing programs), or making major modifications to existing systems (such as providing express bus lanes on existing arterials or adding a new traffic signal or making routine maintenance). Though not presented in this report, the procedures for calculating capital and operating costs are well documented (see References 8 and 9).

Initial transit expenditures can often mean the success or failure of a system. Marketing costs, for example, could influence ridership on new or existing transit systems, thus determining whether fare-box revenues will succeed in meeting operating costs over the long term. While this may or may not be the case at particular Naval installations, it is possible to measure the marketing effectiveness by monitoring recent transportation marketing efforts and record the results over time.

Step 6: Identification of Land Use Relationships--Compared with the above criteria, the land use directly associated with commute travel is difficult to analyze objectively. Most transportation networks and rights-of-way have been in existence in urban areas much longer than current commute patterns dictate. Basic network patters (rights-of-way) were designed to facilitate movement into and through cities. The physical characteristics of the roadways, however, are more dependent on the amount of flow in a given direction, and it is this aspect of land use that model shift (or ride sharing) can affect most dramatically. For example, the option of providing public transit or encouraging ride sharing may receive more weight in the evaluation if a commute corridor is heavily congested and faces the necessity of adding a lane or improving traffic control devices.

Land-use planning and restrictive zoning can also serve to influence roadway characteristics by encouraging residential and commercial/industrial patterns that are more or less conducive to alternative modes of travel. Industrial parks and high-density residential areas, for example, are compatible with large-volume arterials or public transportation

systems, where low-density, single-family developments and randomly sited commercial establishments are better suited to private automobile use.

In recent years, several innovative land-use techniques have served to influence transportation development patterns. Some of these include fiscal incentives for increased center city development such as the Urban Renewal Program and Community Development Program instituted by the Department of Housing and Urban Development, and other incentives such as the no- or low-cost parking facilities along transportation corridors (commonly referred to as park-and-ride lots) for transit patrons and ride-sharing programs. Disincentive land-use programs are also being tried, such as limiting parking accommodations near large work locations. These disincentive programs are being encouraged by the Environmental Protection Agency in their parking management guidelines for metropolitan areas.

The method for determining the relationship between land-use and various transportation options is to first establish a baseline of existing land-use characteristics along the commute corridor being analyzed and then estimate the changes associated with each option considered. Data requirements and calculations are identified on Data Sheet 6.

Step 7: Obtain Cumulative Per-Vehicle Factors--Once the baseline data have been established for each of the criteria being measured, a summary sheet should be prepared (Data Sheet 7) that presents the comparative factors for existing transportation conditions.

Step 8: Interpretation of Baseline Results--When the baseline analysis has been completed, all the necessary information will be at hand to assess network traffic characteristics existing before the introduction of a given transportation option. The baseline data provide several types of useful information:

- The relative desirability of alternative commute routes can be assessed in terms of travel time, degree of interruption, and fuel economy.
- Points of introduction of optional vehicle modes along a specific route can be chosen to maximize savings in fuel and militage air quality problems.
- Per-vehicle pollutant emission and fuel consumption factors, as well as user costs, can be derived from baseline demand volumes for direct application to a variety of options.
- Estimates can be made of types and volumes of model shifts required to achieve desired results.
- The relative effectiveness of transit versus nontransit alternatives can be assessed.
- The overall need to change existing commute patterns can be rationally discussed in terms of quantified alternatives.

Manual Screening--Analysis of Options

Once the baseline has been established, a variety of alternatives to baseline commute patterns can be tested for relative effectiveness in terms of fuel economy and marginal costs as well as air quality and land use improvements. The general approach for fuel consumption and air quality is to obtain the change in traffic volumes on each link of a given commute route resulting from the introduction of an alternative transit mode or travel pattern. Fuel consumption and air quality resulting from the altered flow can then be compared with baseline or with companion options to assess relative effectiveness. This analysis can be performed quite rapidly with cumulative per-vehicle factors derived from the baseline analysis, using Data Sheet 7 in accordance with the accompanying instructions. Commute costs, as described above, are calculated by passenger-miles traveled for each transportation option and measured against the baseline costs. Specific land use implications of alternative options, such as parking requirements, are measured where possible. Other relationships are hypothesized for each option and compared with existing conditions.

Market Area Determination--For each option being considered, appropriate market areas must be chosen. An origin-destination survey must be made to determine the existing and potential locations of candidate commuter populations and their customary routes and modes of travel. In addition to availability of candidate commuters, an important consideration in marketability will be ease of commute. From the information contained in Appendix A and from the link speed and delay data on Data Sheet 1, difficult commute routes can be identified to aid in the marketability studies. Land-use availability will be an important consideration when assessing the marketability of a developing corridor.

Route Selection--When the market areas have been established, it will be necessary to select possible routes (successions of links) affected by the option. Examples would be possible routes for express buses, carpools, and vanpools, or routes traveled by subjects of proposed staggered working hour programs. In determining volume alteration, optional mode routes will be used in conjunction with existing routes from which candidate commuters will be drawn. Consequently, the origin-destination survey, which serves as the basis for selecting option service areas, must include specific information on total route of travel from origin to destination, along with accurate work hours data.

Volume Alteration--Once the appropriate routes have been selected, the volume alteration on each link must be determined. Links will undergo net volume reduction as commuters change modes. Some of these will have their volume reductions slightly offset by the addition of vans, buses, or other multipassenger vehicles. On the basis of relative fuel consumption and pollutant emissions, a bus may be considered equivalent to 3 and a van to 1.5 passenger cars (see References 10 and 11).

Fuel Consumption and Air Pollution--When the volume alterations have been determined, corresponding changes in fuel consumption and air quality can be determined for the route in question. Per-vehicle factors determined from the baseline should normally be of sufficient accuracy if relative comparisons are to be made. On greatlv congested links where volume alteration may conceivably change operating characteristics to the benefit of the entire link volume, calculations in terms of the altered volume can be performed.

DATA SHEETS AND INSTRUCTIONS

Data Sheet 1

PRIMARY INPUT INFORMATION
(STUDY HOUR)

Link I.D. No.	Link Demand Volume (vehicles per hour)	Link Length (miles and tenths)	Vehicle Miles Traveled	Operating Speed (miles per hour)	Stopping Rate (vehicles per hour)	Intersection Delay (seconds)	Average Queue Length (meters)

Data Sheet 2

NETWORK FUEL CONSUMPTION EATIMATION
(STUDY HOUR)

Link I.D. No.	Cruise Mode Consumption (gallons)	Delay Mode Consumption (gallons)		Total Consumption (gallons)
		Idle	Speed Change	
(1)	(2)	(3)	(4)	(5)

INSTRUCTIONS FOR DATA SHEET 2

NETWORK FUEL CONSUMPTION ESTIMATION

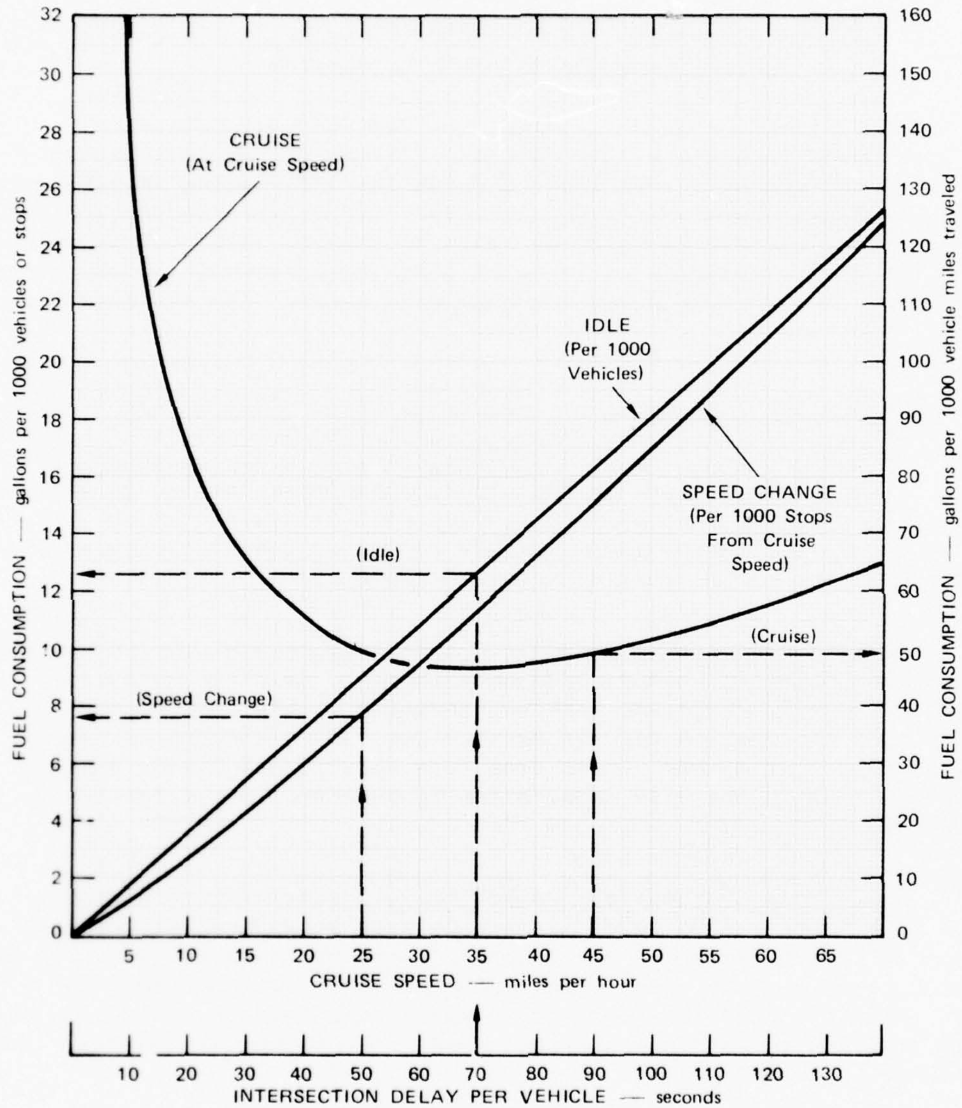
Data Sheet 2 consists of 5 columns. Column (1) is self explanatory, indicating the number of the link to which the information in subsequent columns applies. Columns (2) through (4) require fuel consumption estimates for the separate operational modes of cruise, idle, and speed change. Column (5) will contain an estimate of total fuel consumption on the link obtained as the sum of the modal consumption rates. The estimates are obtained as follows:

- Cruise Mode Consumption. Using Figure 5, enter at the bottom with the link cruise speed in miles per hour from Data Sheet 1. Proceed vertically to intersect the Cruise curve, then proceed horizontally to the right to obtain the cruise mode fuel consumption rate in gallons per 1,000 vehicle miles. Multiply this value by link vehicle miles from Data Sheet 1 and divide the product by 1,000 to obtain the cruise consumption in gallons. Enter the results in column (2).

- Delay Mode Consumption--Idle. Enter Figure 5 at the bottom with intersection delay in seconds from Data Sheet 1. Proceed vertically to intersect the Idle curve and then horizontally to the left to obtain the average idle consumption rate in gallons per 1,000 vehicles. Multiply this value by link demand volume from Data Sheet 1 and divide the result by 1,000 to obtain the idle consumption in gallons. Enter the result in column (3).

- Delay Mode Consumption--Speed Change. Enter Figure 5 at the bottom with intersection delay in seconds from Data Sheet 1. Proceed vertically to intersect the Speed Change curve and then horizontally to the left to obtain the speed change consumption rate in gallons per 1,000 stops. Multiply this value by the stopping rate from Data Sheet 1 and divide by 1,000 to obtain the speed change consumption in gallons. Enter the result in column (4).

- Total Consumption. Sum columns (2), (3), and (4) to obtain the total fuel consumption on the link during the study hour. Enter the result in column (5).



NOTE: Dashed lines illustrate calculation procedure.

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FIGURE 5 GRAPHICAL FUEL CONSUMPTION CALCULATION

Data Sheet 3

NETWORK POLLUTANT EMISSION ESTIMATION
(STUDY HOUR)

Link I.D. No. (1)	Carbon Monoxide Emissions			Total CO Emissions (kilograms) (5)	Hydrocarbon Emissions			Total HC Emissions (kilograms) (9)
	Cruise Mode Emissions (2)	Delay Mode Emissions (kilograms)			Cruise Mode Emissions (6)	Delay Mode Emissions (kilograms)		
		Idle (3)	Speed Change (4)			Idle (7)	Speed Change (8)	

INSTRUCTION FOR DATA SHEET 3

NETWORK POLLUTANT EMISSION ESTIMATION

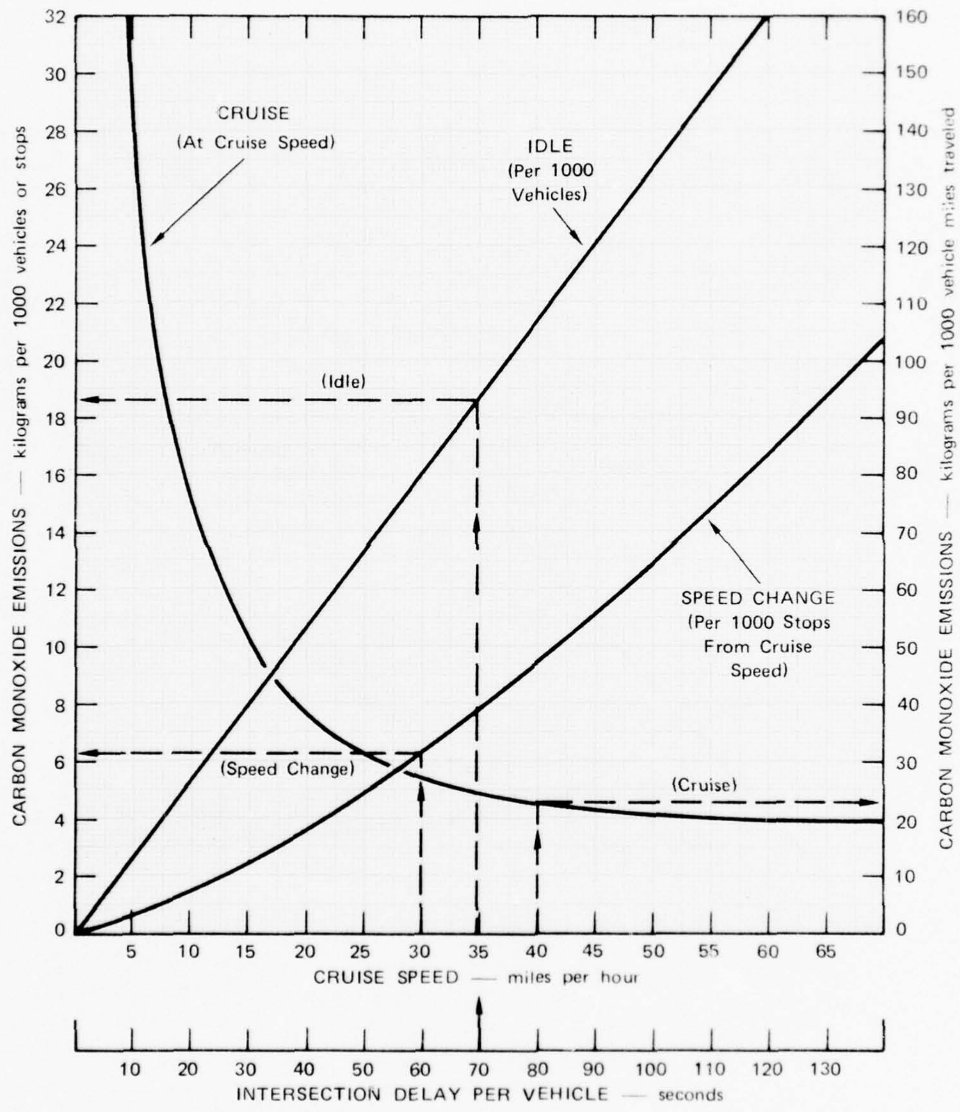
Data Sheet 3 consists of 9 columns. Column (1) is self-explanatory, indicating the number of the link to which the information in subsequent columns applies. Columns (2) through (4) and (6) through (8) require pollutant emission estimates for the separate operational modes of cruise, idle, and speed change. Columns (5) and (9) will contain estimates of total pollutant emission on the link obtained as the sum of the modal emission rates. The estimates are obtained as follows:

- Cruise Mode Emissions. Using Figure 6 or Figure 7, as appropriate, enter at the bottom with the link cruise speed in miles per hour from Data Sheet 1. Proceed vertically to intersect the Cruise curve, then proceed horizontally to the right to obtain the cruise mode emission rate in kilograms per 1,000 vehicle miles. Multiply this value by link vehicle miles from Data Sheet 1 and divide the product by 1,000 to obtain the cruise mode emissions in kilograms. Enter the result in column (2) or (6).

- Delay Mode Emission--Idle. Enter Figure 6 or 7 at the bottom with intersection delay in seconds from Data Sheet 1. Proceed vertically to intersect the Idle curve and then horizontally to the left to obtain the average idle emission rate in kilograms per 1,000 vehicles. Multiply this value by link demand volume from Data Sheet 1 and divide the result by 1,000 to obtain the idle emission in kilograms. Enter the result in column (3) or (7).

- Delay Mode Emission--Speed Change. Enter Figure 6 or 7 at the bottom with intersection delay in seconds from Data Sheet 1. Proceed vertically to intersect the Speed Change curve and then horizontally to the left to obtain the speed change emission rate in kilograms per 1,000 stops. Multiply this value by the stopping rate from Data Sheet 1 and divide by 1,000 to obtain the speed change emission in kilograms. Enter the result in column (4) or (8).

- Total Emission. Sum columns (2), (3), and (4) and columns (6), (7) and (8) to obtain the total pollutant emission on the link during the study hour. Enter the sums in columns (5) and (9).



NOTE: Dashed lines illustrate calculation procedure.

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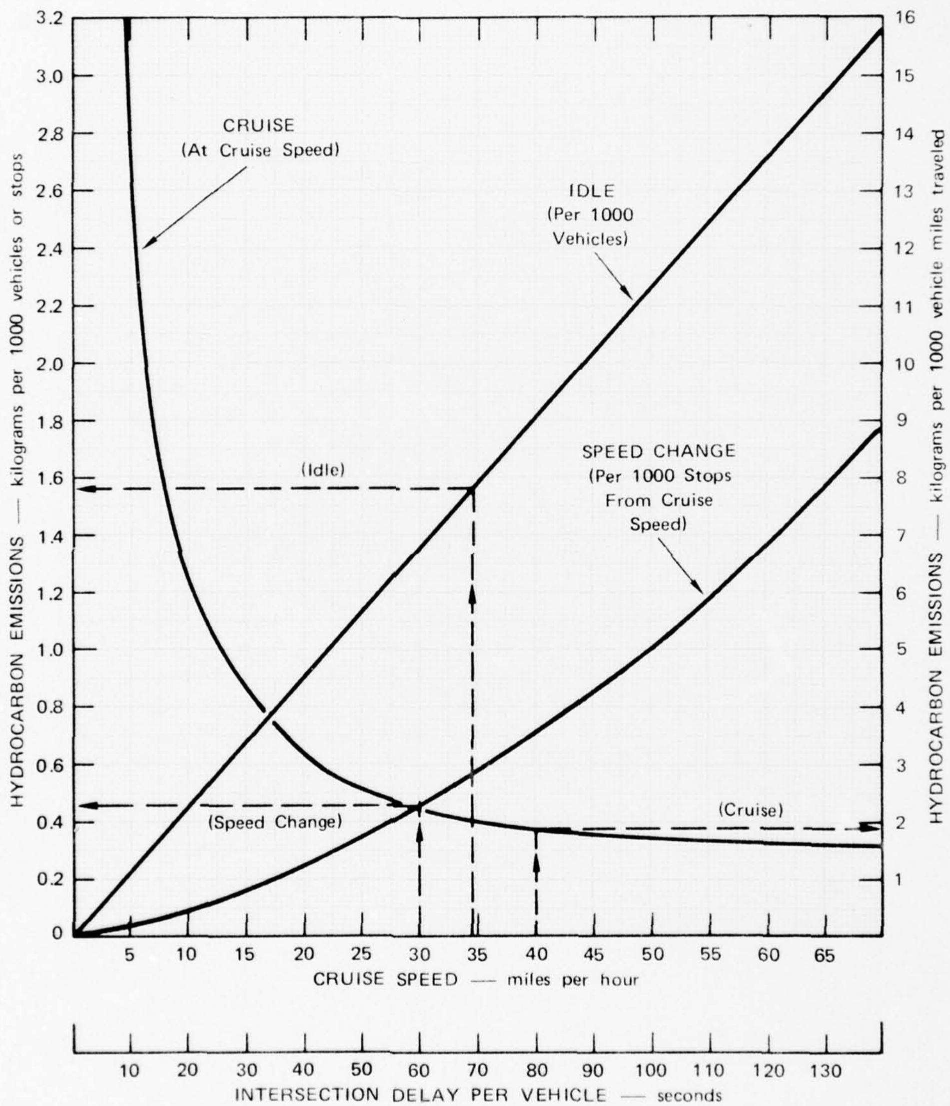
FIGURE 6 GRAPHICAL CALCULATION OF CARBON MONOXIDE EMISSIONS



NOTE: Dashed lines illustrate calculation procedure.

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FIGURE 7 GRAPHICAL CALCULATION OF HYDROCARBON EMISSIONS

Data Sheet 4

LOCAL CARBON MONOXIDE CONCENTRATION ESTIMATION
(STUDY HOUR)

Link I.D. No.	Worst Case Background Concentration (milligrams per cubic meter)	Link Contribution					Total Impact (milligrams/cubic meter)	
		Emission Density (grams per meter per second)			1-Hour Concentration (milligrams/cubic meter)			
		Cruise	Delay	Total	Mid-Block	Inter-section	Mid-Block	Inter-section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

INSTRUCTIONS FOR DATA SHEET 4

ESTIMATING LOCAL CARBON MONOXIDE CONCENTRATIONS

Data Sheet 4 consists of 9 columns. In the column headed Background, an estimate should be entered of worst-case 1-hour average background concentration appropriate to the study hour and location of each link. These values should be obtained from state or local air pollution control officials or estimated with professional assistance. Once the background has been estimated, the remaining columns on the form may be filled out to estimate the local concentration added to background by vehicular emissions on a given road link.

The first step in the localized analysis is to estimate a quantity called emission density, which is the amount of pollutant emitted per meter of link length and per second of time. Emission density is computed separately for cruise and delay (speed change plus idle) modes. The emission density for cruise mode can be obtained from Data Sheets 1 and 3 by dividing carbon monoxide cruise emissions by a factor A, where

$$A = 5796 \times \text{LINK LENGTH}.$$

The emission density for delay mode can be obtained from Data Sheets 1 and 3 by dividing carbon monoxide delay emissions by a factor B, where

$$B = 3.6 \times \text{QUEUE LENGTH}.$$

As the appropriate emission densities for cruise and delay modes are obtained for each link, they should be entered in columns (3) and (4) on Data Sheet 4 and added to provide the total emission density, which is entered in column (5). This total value is assumed to apply on the intersection approach over a distance equal to the queue length. The emission densities obtained can then be used to estimate roadside concentration as follows:

- To obtain a roadside concentration estimate at an intersection approach, multiply total emission density by 145 to obtain the concentration in milligrams per cubic meter. Enter the value obtained in column (7) of the Data Sheet.

- To obtain a roadside concentration estimate along a link with uninterrupted flow (no signals or signs) or at midblock (between intersections) along an interrupted link, multiply the cruise emission density by 145 to obtain the concentration in milligrams per cubic meter. Enter the value obtained in column (6) of the data sheet. The value 145 is based on estimates made with the EPA's HIWAY model (Reference 6), assuming a wind blowing at an angle of 30 degrees to the link direction at a speed of 2 meters per second. Contributions from road links and sources

of carbon monoxide other than the link in question are assumed to be accounted for in the background estimate.

After the estimates of background and link contribution have been entered on the data sheet, they should be added to obtain the total impact, which is entered in columns (8) and (9). This impact value should not be considered representative of a wide region surrounding the link. It applies only to the immediate vicinity of the link itself and is intended as a comparative index of effectiveness for testing travel options.

Data Sheet 5

COMMUTER COST ESTIMATION

Commute Corridor		Establish Average Mileage for Aggregate Link (3)	Average Daily Mileage Cost by Mode (4)				Annual Commuter Costs by Mode of Travel (5)			
Link I.D. No. (1)	Aggregate Commute Links (2)		Single-Occupant Car	Carpool	Vanpool	Bus	Single-Occupant Car	Carpool	Vanpool	Bus

INSTRUCTIONS FOR DATA SHEET 5

COMMUTER COST ESTIMATION

Data Sheet 5 consists of 5 basic columns, with subdivisions under two categories to delineate the differences between individual modes of travel. Information to complete columns (2), (3), and (4) is given below; column (5) is the result of multiplying columns (3) and (4) and then adding toll or parking fees to find total daily commute costs. Annual costs are established by multiplying daily costs by 240 work days. Commuter cost estimates are obtained as follows:

- Aggregate Commute Links. For purposes of figuring commuter costs the separate commute links identified in Figure 2 are aggregated to represent average trip distances for commuters using each corridor. For example, in the Tidewater case there would be three distinct aggregate commute links: one beginning in Portsmouth at intersection 5 and running to Sewells Point--approximately 9.2 miles; the second link beginning in Virginia Beach at intersection 31 and running the Sewells Point--approximately 16.8 miles; and the third beginning in Norfolk at intersection 24 to Sewells Point--some 5.8 miles. Assign some identifying code in column (2) for each aggregate link and enter the corresponding mileage distance in column (3) for each link identified. Multiply by 2 to obtain round-trip mileage.

- Average Cost Per Mile by Mode of Travel. Use the following data* and instructions to complete column (4).

  - Auto: marginal costs = 10.3 cents per mile (includes 3.8 cents for fuel, oil, and tires and 5.5 cents for maintenance and repairs); full costs = 18.9 cents per mile (includes license, insurance, interest, and depreciation).
  - Carpool: 10.3 or 18.9 cents divided by 3 = 3.4 or 6.3 cents per mile.
  - Vanpool: 5 cents per mile (includes amortized vehicle costs, fuel, oil, tires, license, and insurance).
  - Bus: Use per-day fare, assuming passengers can walk to their pick-up point.

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*These costs should be updated annually. The source for the figures quoted in this report is Hertz Company annual auto operating cost report.

Calculations:

- Auto: Multiply daily round-trip mileage [column (3)] by per-mile costs (above) to obtain daily mileage costs. Add any toll or parking fees. Show both marginal costs and full costs.
- Carpool: Repeat auto calculation and divide by average numbers of riders--2, 3, or 4.
- Vanpool: Multiply daily round-trip mileage by 5-10 cents (depending on established per-mile rate for the area) to obtain daily mileage costs. Add one-twelfth of toll and parking fee if applicable.
- Bus: Multiply one-way fare by 2 to obtain daily fare.

• Annual Commuter Costs by Mode of Travel. Multiply column (4) by 240 days to obtain annual average commuter costs for each mode of travel.

Data Sheet 6

LAND USE RELATIONSHIPS

Commute Corridor Market Area (1)	Existing Land Use (acres) (2)					Parking Area Required by Mode of Travel at Work Location (3)			
	Residential	Commercial	Industrial	Undeveloped (open space)	Right-of-Way for Corridor	Auto	Carpool	Vanpool	Bus

INSTRUCTIONS FOR DATA SHEET 6

LAND USE RELATIONSHIPS

Data Sheet 6 consists of three basic columns of information: (1) a definition of commute corridor market areas, (2) a quantitative (acres) description of existing land-use categories for each market area identified, and (3) a quantitative description of parking requirements at the work location for each mode of commute travel. Land-use estimates are obtained as follows:

- Identify Market Area. Market areas are defined by assessing existing and potential locations of candidate commute populations. Existing commute patterns can be obtained from origin-destination survey data. For purposes of analysis it is best to establish boundaries of market areas according to residential distribution of commuters (for example, carpoolers and vanpoolers should live within 1-4 miles of one another) and within a feasible access area to the transportation corridor being studied.

- Identify Existing Land-Use Characteristics. Contact local and regional planning agencies to obtain land-use maps and data for each of the market areas identified in column (1). Population land-use data may be available by census tract or by another predetermined grid pattern. Calculate the acreage of land under each of the categories in column (2) for each market area.

- Parking Requirements. Refer to origin-destination survey (Appendix B) to obtain an estimate of commute patterns by mode. Now calculate the parking space (in square feet) required for each passenger (commuter) using the following estimates:

1 single-passenger automobile = 120 sq ft

1 carpooler (1 single-passenger vehicle ÷ 3) = 40 sq ft

1 vanpooler (150 ÷ 12) = 12.5 sq ft

1 public bus rider (40 ÷ 40) = 10 sq ft

Data Sheet 7

COMPILATION OF PER-VEHICLE FUEL CONSUMPTION AND POLLUTANT EMISSION FACTORS
(STUDY HOUR)

Link I.D. No. (1)	Link Demand Volume (vehicles per hour) (2)	Link Fuel Consumption per 100 Vehicles (gallons) (3)	Link Pollutant Emission per 100 Vehicles (kilograms)		Cumulative Fuel Consumption and Pollutant Emissions per 100 Vehicles*		
			Carbon Monoxide (4)	Hydrocarbons (5)	Fuel (gallons) (6)	Carbon Monoxide (kilograms) (7)	Hydrocarbons (kilograms) (8)

*One-way: origin to desination.

INSTRUCTIONS FOR DATA SHEET 7

COMPILATION OF PER-VEHICLE FUEL CONSUMPTION AND POLLUTANT EMISSION FACTORS

Data Sheet 7 consists of 8 columns. In column (1) the numbers of all links along a given commute route should be entered in order, beginning at and proceeding away from the route destination. Only links directed toward the destination should be listed. In columns (2) through (5) entries are made of demand volume, total per-vehicle fuel consumption, and total per-vehicle pollutant emissions for each link. Per-vehicle values are obtained by dividing the appropriate link totals from Data Sheets 2 and 3 by link demand volume. In columns (6) through (8), cumulative sums of the link-by-link per-vehicle values are entered, beginning with the destination link. These cumulative values indicate the fuel consumed or pollutant emitted by a vehicle entering the route at the upstream end of a link and proceeding along the route to the destination.

METHODOLOGY DEMONSTRATION

As a test of its reasonableness and a demonstration of its applicability to a real situation, we employed the methodology in an analysis of simulated transportation options for the Tidewater area. Two corridor routes were chosen as simple network forms. One route, approximately 23 miles long, begins at the shore in Virinia Beach and ends at the intersection of Admiral Taussig Boulevard and Hampton Boulevard at Sewells Point. This route is characterized by uninterrupted flow along limited-access roadways. The second route, approximately 14 miles long, begins at the intersection of High Street and Collins Boulevard, Portsmouth, and ends at the intersection of Admiral Taussig Boulevard and Bainbridge Avenue at Sewells Point. This route was chosen because of its service to a developing area in Portsmouth and farther west in Suffolk. It is also of interest as a route characterized by interrupted flow due to a variety of controlled intersections and a toll tunnel (Midtown Tunnel). The two routes are shown in Figure 1.

Once the routes were chosen, available data were gathered on the physical and operational characteristics of the roadways. Hourly traffic counts were obtained from the Virginia Department of Highways and Transportation, and information on roadway dimensions and intersection control devices was obtained from local traffic agencies in Portsmouth, Norfolk, and Virginia Beach with the help of the Navy Facilities Engineering Command. The Navy also provided traffic studies and origin-destination data related to Sewells Point.

Based on the information available to us, we applied the methodology described earlier, along with the worksheets in Appendix A and figures in Appendix D, to an analysis of the morning peak commute hour (7-8 a.m.) as a baseline. Three study segments were selected from the two corridor routes, as described in Appendix B. The peak-hour data as derived through the methodology are included as Appendix C. In applying the methodology it was assumed, for the sake of simplification, that all traffic used the through lanes at intersections and that activated signals were fixed at maximum cycle and minimum phase length. Based on the peak-hour results, a per-vehicle average of fuel consumption and pollutant emission was obtained for each link and a cumulative total obtained between each route intersection (treated as an origin point) and the Sewells Point route terminus. The cumulative per-vehicle values are given in Tables 4 and 5. Commuter costs (Table 7) and land use relationships (Data Sheet 6, Appendix B) were also assessed for existing commute patterns.

To demonstrate the testing of options, six hypothetical but plausible scenarios were developed as outlined in Appendix B. Each scenario involves mode switching within a commute option market area along one of the two

corridor routes. The result of the mode switching is a change in the number of vehicles entering the corridor route. By apportioning the vehicle alterations to specific intersections as entry points, the per-vehicle factors in Tables 4 and 5 were used to estimate total fuel consumption and pollutant emission between scenario origin and destination, and ambient roadside carbon monoxide concentration at the worst intersection along the route. The results, as summarized in Tables 6 and 7, enable a comparison of the relative effectiveness of options from an environmental protection standpoint.

Table 4

CUMULATIVE FUEL CONSUMPTION AND POLLUTANT EMISSION*
FACTORS FOR TIDEWATER COMMUTE CORRIDOR I
(Morning Peak Commute Hour)

Possible Commute Origin Intersections*	Fuel Consumption per 100 Passenger Cars (gallons)	Pollutant Emission per 100 Passenger Cars (kilograms)	
		CO	HC
35	104.8	49.4	4.6
34	98.4	47.0	4.4
33	83.6	41.2	3.9
32	77.6	38.7	3.7
31	69.3	35.2	3.4
30	58.2	29.6	2.9
29	52.0	26.4	2.6
28	44.8	22.6	2.2
27	41.0	20.6	2.0
26	32.9	16.4	1.6
25	28.8	13.9	1.3
24	23.1	10.9	1.0
23	18.7	8.7	0.8
22	14.4	6.6	0.6
21	10.1	4.6	0.4
20	--	--	--
19	--	--	--
18	--	--	--
17	--	--	--
16	--	--	--

*See Figure 2.

Table 5

CUMULATIVE FUEL CONSUMPTION AND POLLUTANT EMISSION*
FACTORS FOR TIDEWATER COMMUTE CORRIDOR 2
(Morning Peak Commute Hour)

Possible Commute Origin Intersections*	Fuel Consumption per 100 Passenger Cars (gallons)	Pollutant Emission per 100 Passenger Cars (kilograms)	
		CO	HC
1	74.8	44.5	3.6
2	73.4	43.8	3.5
3	68.8	41.3	3.3
4	57.8	35.3	2.9
5	55.5	33.9	2.8
6	52.7	32.6	2.6
7	48.5	31.0	2.5
8	42.3	28.0	2.2
9	36.2	24.2	2.0
10	34.5	22.4	1.9
11	29.9	19.6	1.7
12	27.7	18.1	1.6
13	23.9	15.7	1.4
14	16.6	11.2	1.0
15	14.9	10.1	0.9
16	4.0	3.5	0.3
17	0	0	0

*See Figure 2.

Table 6

COMPARATIVE IMPACT OF OPTIONS

Option Identification*		Commute† Volume	Vehicle Mileage‡ (vehicle miles† traveled per year)	Fuel Consumption†‡ (gallons per year)	Air Pollutant Emissions‡ (metric tons per year)		Roadside Carbon Monoxide Concentration§ (milligrams per cubic meter)
					CO	HC	
Existing	(1a)	2,074	3,874,752	208,064	97.5	8.0	6.6
1	(1a)	1,344	2,491,587	134,830	63.2	5.1	4.2
2	(1a)	1,768	3,295,650	177,366	83.2	6.7	5.5
Existing	(1b)	2,012	12,724,992	611,326	307.1	25.6	6.1
1	(1b)	1,932	12,201,846	587,019	294.9	24.6	5.9
2	(1b)	1,390	8,838,372	357,619	212.2	17.7	4.2
Existing	(2)	1,035	4,685,184	266,285	163.9	13.6	18.3
1	(2)	929	4,203,962	239,013	147.2	12.3	17.3
2	(2)	723	3,275,845	186,013	114.5	9.5	16.9

*See Appendix B for definitions.

†Equivalent passenger cars. Buses and vans are included assuming an equivalence of 3 cars per bus and 1.5 cars per van.

‡All annual computations assume a 240-day commute year.

§Concentrations apply at roadside for links 64-76 on corridor segment 1a; for links 78-90 on corridor segment 1b; and for link 32 at the intersection of Hamptbon Boulevard and 38th Avenue on corridor 2.

Table 7

COMMUTER COSTS FOR TIDEWATER COMMUTE
CORRIDORS 1a, 1b, AND 2
(Annual Costs per Commuter)

		Single-Passenger Auto		Carpool (with 3 riders)	Vanpool	Bus
Corridor 1a (5.8 miles)	m*	$ 285.60	m	$ 95.20	$139.20	$264.00
	f*	526.18	f	175.39		
Corridor 1b (16.8 miles)	m	950.40	m	316.80	403.20	312.00
	f	1,644.00	f	548.00		
Corridor 2 (9.2 miles)	m	576.00	m	192.00	220.80	288.00
	f	955.20		318.40		

*m - marginal costs
f - full costs

PROCESS AUTOMATION

Up to this point we have dealt with the development and use of manual analysis techniques for impact assessment. Manual techniques provide a number of benefits, among which are:

- Minimization of analysis cost
- Familiarization with the analytic processes
- Flexibility of application.

Beyond a certain limit, however, the manual approach becomes cumbersome and tedious as the analysis elements (links and intersections) and the combinations in which they are used (routes and options) increase in number. Therefore, to produce the most generally applicable system practicable, an automated (computerized) version of the analysis methodology is desirable. This section describes in brief the computerized methods developed in the project. This automated approach is intended to complement rather than replace the manual approach. The automated models for pollutant emissions and fuel consumption are essentially the same as the models used in the manual approach. The principal advantage of automation lies in the ability to handle complex, extensive, and repetitive analysis problems.

As the basis for process automation, we have combined elements of two existing SRI computer programs. The first of these programs, ISMAP, takes as input the same physical characteristics of links and intersections used as input to the manual approach, except that link lengths are computed internally on the basis of geographic coordinates supplied for the end points of each link. Based on these inputs, ISMAP computes vehicle mileage, travel time, and delay on each link. These computed operational characteristics are then used by the program to estimate carbon monoxide emissions for various portions of the link associated with the operational modes of cruise, idle, and speed change. Finally, the emissions are used by the program to estimate carbon monoxide concentration at designated receptor points.

In these respects, the computer program "mimics" the manual approach. The automated version does, however, possess an additional degree of sophistication in several areas: vehicle-actuated signalization at intersections and least-time routing over the network can be accommodated, in conjunction with quantitative zonal trip production and attraction information. Routing to parking areas within destination zones based on available space can also be accommodated. Finally, the program can be run iteratively for a number of hours on time segments as short as 15 minutes to track the ebb and flow of traffic.

As the basis for automated fuel consumption estimates, we have employed our program LNKMOD as a subroutine to program ISMAP. Fuel consumption estimates by LNKMOD are based on the carbon content of auto exhaust emissions. The program calculates the total weight of hydrocarbons, carbon monoxide and carbon dioxide emitted on each link of the network. Fuel consumption is then calculated on the basis of a regression equation fitted to field data obtained by the EPA in 1971. The regression coefficients currently used in the program are based on a vehicle mix, weighted by model class, appropriate to the time period (pre-1971) when the field testing was performed. Consumption estimates are amenable to refinement by tuning the vehicle mix to a given locale and calculation year. Current fuel consumption is probably slightly understated by the model because of the inroads on fuel economy made by pollution control devices and unaccounted for in the regression model. Program improvements in fuel consumption, however, should work in the opposite direction and improve the accuracy of the model. We feel that the model in its current form will be suitable for relative comparisons between options in the absence of radical changes in auto fuel consumption rates.

The hybrid model described above has been named NAFCOM (Network Air Pollution and Fuel Consumption Model). The structure of this program is such that both pollutant emissions and fuel consumption are available as totals on each link, with carbon monoxide emissions further broken down by the operational modes of cruise, idle, and speed change. The program can, therefore, be used on a one-time basis to generate baseline per-vehicle emissions and fuel consumption as input to manual evaluation of transportation options. Alternatively, the program can be used directly to evaluate individual options in a fully automated manner. The combination of manual and automated techniques provides considerable flexibility.

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Appendix A

OPERATIONAL CHARACTERISTICS OF NETWORK TRAFFIC FLOW

Appendix A

OPERATIONAL CHARACTERISTICS OF NETWORK TRAFFIC FLOW

To estimate the fuel consumption and pollutant emission characteristics of candidate highway commute options, it is necessary to determine certain conditions of traffic flow experienced by a typical vehicle on the network. When traffic flows freely, facilitated by low traffic volume or good roadway design, congestion will be minimized, as will fuel consumption and air pollutant emissions. When congestion occurs, in the case of heavy traffic or poor roadway design, fuel consumption and pollutant emissions are increased because of additional travel time and less efficient operation of the automobile engine.

In general, the problem of network design and traffic flow is a complex one. Its full treatment is beyond the scope of this report, and interested readers are referred to References 12 and 13. There are, however, basic characteristics of traffic flow which, even without professional assistance, can be estimated by a nonprofessional for environmental screening of candidate transportation options. The methodology presented here is based primarily on the material presented in the Highway Capacity Manual (Ref. 12), with adaptions developed in References 1 through 4 and Reference 13. The object of the methodology is the estimation of two key flow characteristics for each network segment (link) affected by a candidate option. The first of these characteristics, which we shall term free flow or cruise speed, is the average speed with which vehicles would traverse the link in the absence of flow interruption at intersections. The second characteristic is the delay, or excess time spent on the link by those vehicles whose flow is interrupted by required stops at toll booths, signals, or signs.

Free Flow Characteristics--The first step in the procedure is the determination of free flow or cruise speed on each link. The calculation can be accomplished and recorded by completing Worksheet A-1 in conjunction with the accompanying instructions and procedures.

Characteristics of Intersection Delay--In addition to the free flow characteristics, each link must be evaluated relative to characteristics of delay experienced at the downstream intersection. Intersection delay can normally be neglected on links where through traffic has the uninterrupted right-of-way. For links on which traffic flow is required to stop for a portion of time by a signal, sign, gate, or toll booth, the basic characteristics of intersection delay can be evaluated using Worksheet A-2 in conjunction with the accompanying instructions and procedures. Worksheet A-2 consists of two parts, Part I for estimating intersection capacity and Part II for estimating characteristics of intersection delay.

WORKSHEET A-1

INSTRUCTIONS

Worksheet A-1 consists of five columns. In the first column is entered an identifying number for each link for which a calculation of cruise speed is to be made. In the last four columns, information for a given link is entered as indicated by the column heading. Numbers in parentheses below the column headings refer to corresponding circled numbered procedures found on the pages immediately following the worksheet. Numbers in brackets indicate an arithmetic operation involving the values contained in appropriately numbered columns of the worksheet.

Worksheet A-1

ESTIMATION OF LINK CRUISE SPEED

Link I.D. No.	Study Hour Demand Volume (vehicles per hour) (1)	Free Flow Capacity (vehicles per hour) (2)	Demand/Capacity Ratio [(1)÷(2)]	Cruise Speed (miles per hour)

WORKSHEET A-1

PROCEDURES

1 The study hour demand volume is the number of vehicles that actually traverse the link in question during a specific hour under study. Link traffic volumes (current or projected) can usually be obtained from a state or local traffic engineering department based on periodic traffic counts or traffic modeling studies. When hour-by-hour traffic information is available, such information can be used directly as the hourly demand volume. When only two-way annual average daily traffic (AADT) is available, as is frequently the case, Figure A-1 can be used to estimate the peak and off-peak demand volumes. To use Figure A-1, enter at the bottom with the two-way AADT per lane pair for the road segment in question, proceed vertically to intersect the appropriate curve and then proceed horizontally to the left to obtain an estimate of the one-way traffic per lane in the peak or off-peak direction. It should be noted that Figure A-1 is valid for a typical road with predominant flow in one direction during the peak hour. Since there are exceptions to the typical situation, hourly traffic information should be sought and used where available.

2 Free flow capacity refers to the maximum number of vehicles that are physically capable of traversing the link in a given hour. Free flow capacity may be estimated as 2,000 vehicles per hour per lane for multi-lane links and 1,000 vehicles per hour for single-lane links, corrected by Tables A-1 and A-2 for roadside obstructions and heavy-duty vehicle use. For the purpose of the capacity calculation, a three-lane road with a shared center lane may be treated as though it were one lane in each direction. The free flow capacity is obtained, then, by multiplying the number of lanes by the appropriate per-lane value corrected in accordance with Tables A-1 and A-2.

3 Cruise speed on a link can be obtained from Figure A-2 on the basis of the type of road and the estimated ratio of demand volume to capacity. To use the figure, enter at the bottom with the ratio of demand volume to link free flow capacity, proceed vertically to intersect the appropriate curve and then horizontally to obtain an estimate of cruise speed. Since Figure A-2 represents typical conditions for a variety of actual road conditions, the estimate could be improved on by the use of observed operating speeds for the road in question, if such information is available.

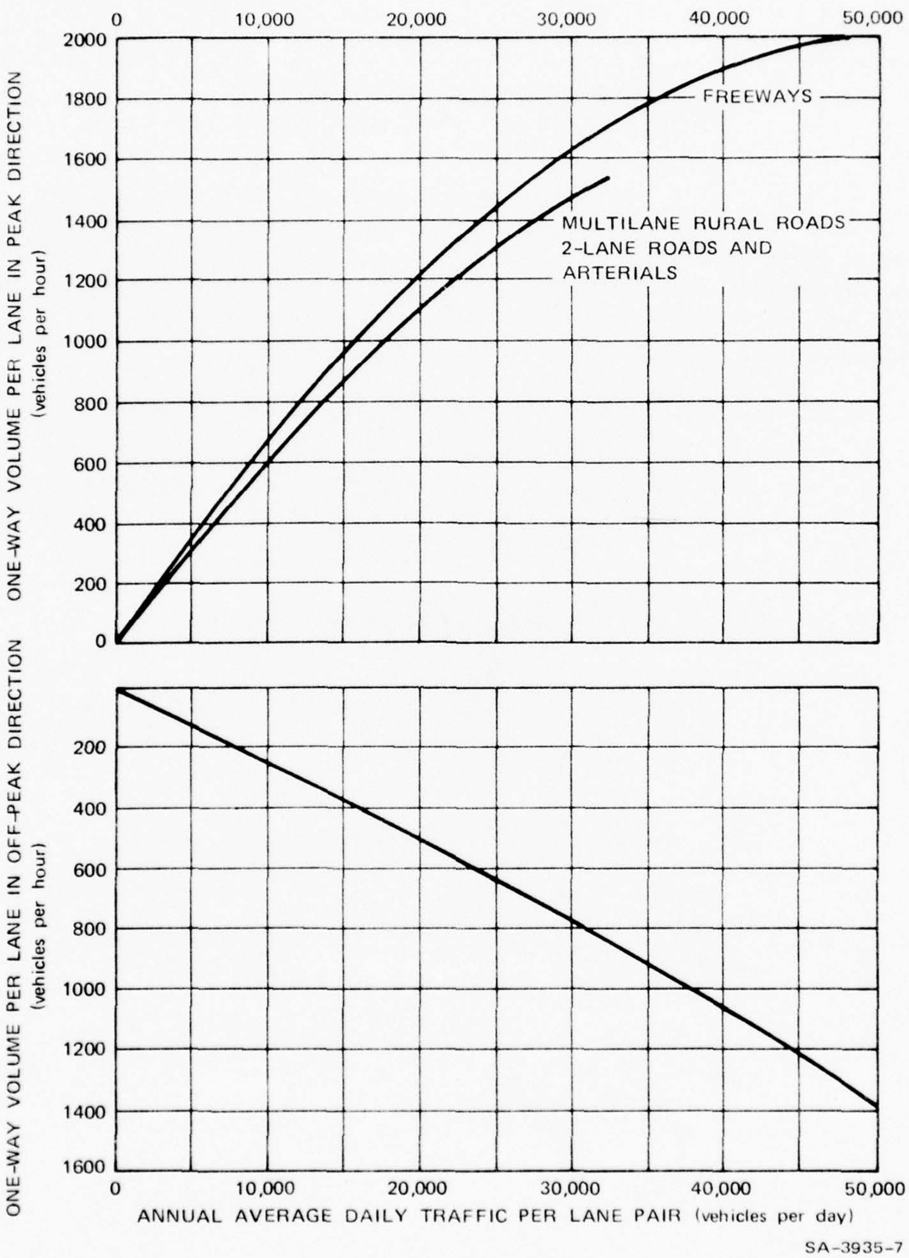


FIGURE A-1 GRAPHICAL ESTIMATION OF ONE-WAY TRAFFIC VOLUMES FOR PEAK DIRECTIONS BASED ON ANNUAL AVERAGE DAILY TRAFFIC

Table A-1

CORRECTION OF FREE FLOW CAPACITY
FOR LANE WIDTH AND ROADSIDE OBSTRUCTION

Distance from Traffic Lane Edge to Obstruction (feet)	Adjustment Factor, W, for Lane Width and Lateral Clearance							
	Obstruction on One Side of One-Direction Roadway				Obstructions on Both Sides of One-Direction Roadway			
	12-Ft Lanes	11-Ft Lanes	10-Ft Lanes	9-Ft Lanes	12-Ft Lanes	11-Ft Lanes	10-Ft Lanes	9-Ft Lanes
(a) 4-Lane Divided Freeway, One Direction of Travel								
6	1.00	0.97	0.91	0.81	1.00	0.97	0.91	0.81
4	0.99	0.96	0.90	0.80	0.98	0.95	0.89	0.79
2	0.97	0.94	0.88	0.79	0.94	0.91	0.86	0.76
0	0.90	0.87	0.82	0.73	0.81	0.79	0.74	0.66
(b) 6- and 8-Lane Divided Freeway, One Direction of Travel								
6	1.00	0.96	0.89	0.78	1.00	0.96	0.89	0.78
4	0.99	0.95	0.88	0.77	0.98	0.94	0.87	0.77
2	0.97	0.93	0.87	0.76	0.96	0.92	0.85	0.75
0	0.94	0.91	0.85	0.74	0.91	0.87	0.81	0.70
(c) 2-Lane Highway, One Direction of Travel								
6	1.00	0.88	0.81	0.76	1.00	0.88	0.81	0.76
4	0.97	0.85	0.79	0.74	0.94	0.83	0.76	0.71
2	0.93	0.81	0.75	0.70	0.85	0.75	0.69	0.65
0	0.88	0.77	0.71	0.66	0.76	0.67	0.62	0.58

Table A-2

AVERAGE GENERALIZED ADJUSTMENT FACTORS FOR
HEAVY-DUTY VEHICLES ON FREEWAYS AND EXPRESSWAYS
AND ON TWO-LANE HIGHWAYS OVER EXTENDED SECTION LENGTHS

Percentage of Heavy-Duty Vehicles	Factor, T, for All Levels of Service: Level Terrain	Rolling Terrain	Mountainous Terrain
(a) Freeways and Expressways			
1%	0.99	0.97	0.93
2	0.98	0.94	0.88
3	0.97	0.92	0.83
4	0.96	0.89	0.78
5	0.95	0.87	0.74
6	0.94	0.85	0.70
7	0.93	0.83	0.67
8	0.93	0.81	0.64
9	0.92	0.79	0.61
10	0.91	0.77	0.59
11	0.89	0.74	0.54
14	0.88	0.70	0.51
16	0.86	0.68	0.47
18	0.85	0.65	0.44
20	0.83	0.63	0.42
(b) 2-Lane Highways			
1%	0.99	0.96	0.90
2	0.98	0.93	0.82
3	0.97	0.89	0.75
4	0.96	0.86	0.69
5	0.95	0.83	0.65
6	0.94	0.81	0.60
7	0.93	0.78	0.57
8	0.93	0.76	0.53
9	0.92	0.74	0.50
10	0.91	0.71	0.48
12	0.89	0.68	0.43
14	0.88	0.64	0.39
16	0.86	0.61	0.36
18	0.85	0.58	0.34
20	0.83	0.56	0.31

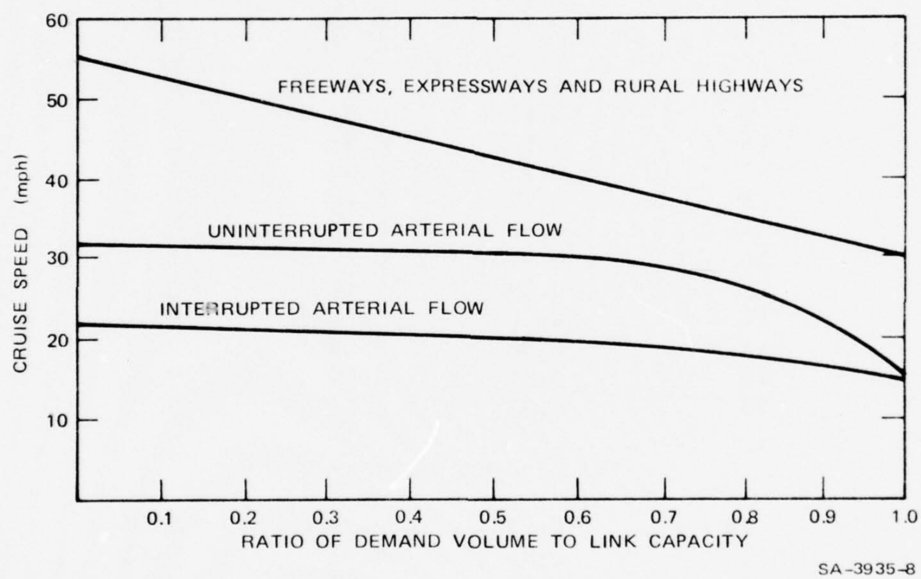


FIGURE A-2 GRAPHICAL ESTIMATION OF CRUISE SPEED AS A FUNCTION OF LINK DEMAND/CAPACITY RATIO

WORKSHEET A-2

INSTRUCTIONS

Worksheet A-2 consists of two parts with a total of 16 columns. The first column in each part requires the entry of an identifying number for each link on which a calculation of delay characteristics is to be made. In the remaining columns, information for each link is entered as indicated by the column heading. Circled numbers below the column headings refer to similarly numbered procedures found on the pages immediately following the worksheet. Circled numbers in brackets indicate an arithmetic operation involving values contained in appropriately numbered columns of the worksheet.

Worksheet A-2

ESTIMATION OF INTERSECTION DELAY
PART I
INTERSECTION CAPACITY

Link I.D. No.	Type of Control (1)	Approach Width (feet) (2)	Metropolitan Population (3)	Urban Location (4)	Cycle Length (seconds) (5)	Green/Cycle Ratio (6)	Saturation Service Volume (veh/hour) (7)	Intersection Capacity (veh/hour) (8)

Worksheet A-2

ESTIMATION OF INTERSECTION DELAY
PART II
CHARACTERISTICS OF INTERSECTION DELAY

Link I.D. No.	Demand Volume (veh/hour) (9)	Demand/ Saturation Ratio (9):(7)	Stopping Rate (veh/hour) (10)	Intersection Delay (seconds) (11)	Queue Length (meters) (12)

WORKSHEET A-2

PROCEDURES

(1) Type of control means the designation of an intersection control device as one of the following:

- Traffic signal
- Stop or yield sign
- Toll booth or gate.

The type of control mandating stops at an intersection will determine the nature of the calculations leading to an estimate of delay.

(2) Intersection approach width is the physical width, in feet, of the road segment under control at the intersection. In the case of signs, gates, or toll booths, it is normally the full width of the intersection approach, although certain segments, such as exclusive turn lanes or bus and carpool lanes, which are free of control, should be excluded. In the case of signals, separate road segments may be controlled by separate signal phases. In such cases, separate approach widths should be used for the individually controlled segments.

(3) Metropolitan population refers to the number of residents of the community or metropolitan area in which the road link of concern is located.

(4) Urban location refers to the specific location, by land use type, of the link of concern within the community or metropolitan area. Location should be designated as one of the following:

- Central Business District--That portion of a municipality in which the dominant land use is intense business activity.
- Fringe--That portion of a municipality immediately outside the central business district, in which there is a wide range of business activity, generally including small commercial, light industrial, warehousing, automobile service activities, and intermediate strip development, as well as some concentrated residential areas.
- Outlying Business District--That portion of a municipality, normally separated geographically by some distance from the central business district and its fringe area, in which the principal land use is for business activity.

- Residential Area--That portion of a municipality, or an area within the influence of a municipality, in which the dominant land use is residential development, but where small business areas may be included.

(5) Cycle length means the time required for a traffic signal to pass through all its phases (green, red, amber, arrows, etc.). Cycle length will frequently change during the course of the day to accommodate the varying traffic volumes. The cycle length used should be that for the hour of concern (usually peak or off-peak).

(6) For a given road segment under control, vehicles will experience a green signal for a certain portion of the total signal cycle. This fraction of green time is called the green/cycle ratio and is expressed as a decimal fraction.

(7) Saturation service volume is the maximum number of vehicles per hour that can theoretically pass through an intersection on the approach segment of concern in the absence of control. The saturation service volume depends on the characteristics dealt with in items (1) through (6) of Worksheet A-2, as well as on turning movements at the intersection and on the percentage of heavy-duty vehicles (trucks and buses) in the traffic stream. Figure A-3 enables its calculation under typical conditions assuming a green/cycle ratio of 1.0.

(8) Intersection capacity means the maximum number of vehicles that can theoretically pass through the intersection on the approach segment of concern given the actual degree of control present. Figure A-3 enables the graphical estimation of capacity for signalized intersection approach segments. Capacity estimates for signed intersections can be obtained from the same figure by treating them as though they were signalized with a green/cycle ratio of 0.75, based on suggestions contained in Reference 12. Traffic halted by a stop or yield sign may proceed through the intersection only at a rate consistent with the volume of the uninterrupted cross-stream traffic. The situation can be handled by defining a quantity that we shall term cross-stream tolerance, equal to the difference between cross-stream free flow capacity and cross-stream demand volume. A correction factor must be applied for signed-intersection capacity. Figure A-3 embodies a graphical application of a correction factor based on cross-stream tolerance. Toll booth capacity is handled on a per-gate basis with a gate capacity (Cg) computed as

$$Cg = \frac{3600}{H} \text{ (veh/gate/hr)} \quad .$$

The quantity H is the gate headway, that is, the average time interval (in seconds) between vehicles leaving the gate.

(9) Route demand volume is defined as the demand volume of traffic on the approach segment constituting the route of interest. As such it might be the entire demand volume on the link, but where a specific route is

being analyzed (such as a commute corridor route to a specific destination), approach segments carrying exclusively traffic turning from the route in question (nonthrough traffic) can be excluded from the capacity and delay analyses.

10 Stopping rate. Depending on the type of control, all or a portion of vehicles encountering the controlled intersection will be required to stop. In the case of signed intersections, it is assumed that 100% of the approaching vehicles stop. In the case of toll booths, a portion of approaching vehicles may have the privilege of uninterrupted movement through the booth. In the case of signalized intersections, the proportion of vehicles stopping will depend on the characteristics of the signal. Figure A-4 enables estimation of the number of vehicles stopping in the hour of concern, based on the ratios calculated in items 6, 7, and 9 of Worksheet A-2.

11 Delay. Because of the interruption occasioned by the characteristics of the intersection, vehicles stopping will experience a delay over the time that would be spent on the link in the absence of interruption to the flow. An average value of delay per vehicle can be obtained from Figures A-5 and A-6, based on information obtained on Worksheet A-2. Toll booth capacity is handled on a per-gate basis with a gate capacity (Cg) computed as

$$Cg = \frac{3600}{H} \text{ (veh/gate/hr)} \quad .$$

The quantity H is the gate headway, that is, the average time interval (in seconds) between vehicles beaving the gate. For toll booths, Figure A-6 should be used in conjunction with individual gate capacity rather than total approach capacity, and a minimum delay equal to gate headway should be assumed.

12 The final item to be calculated is the queue length or the average length of the line of cars waiting at an intersection. Queue length is related to average vehicle delay and the capacity per lane of the intersection approach. Figure A-7 enables a graphical estimate of queue length based on information from earlier columns of Worksheet A-2.

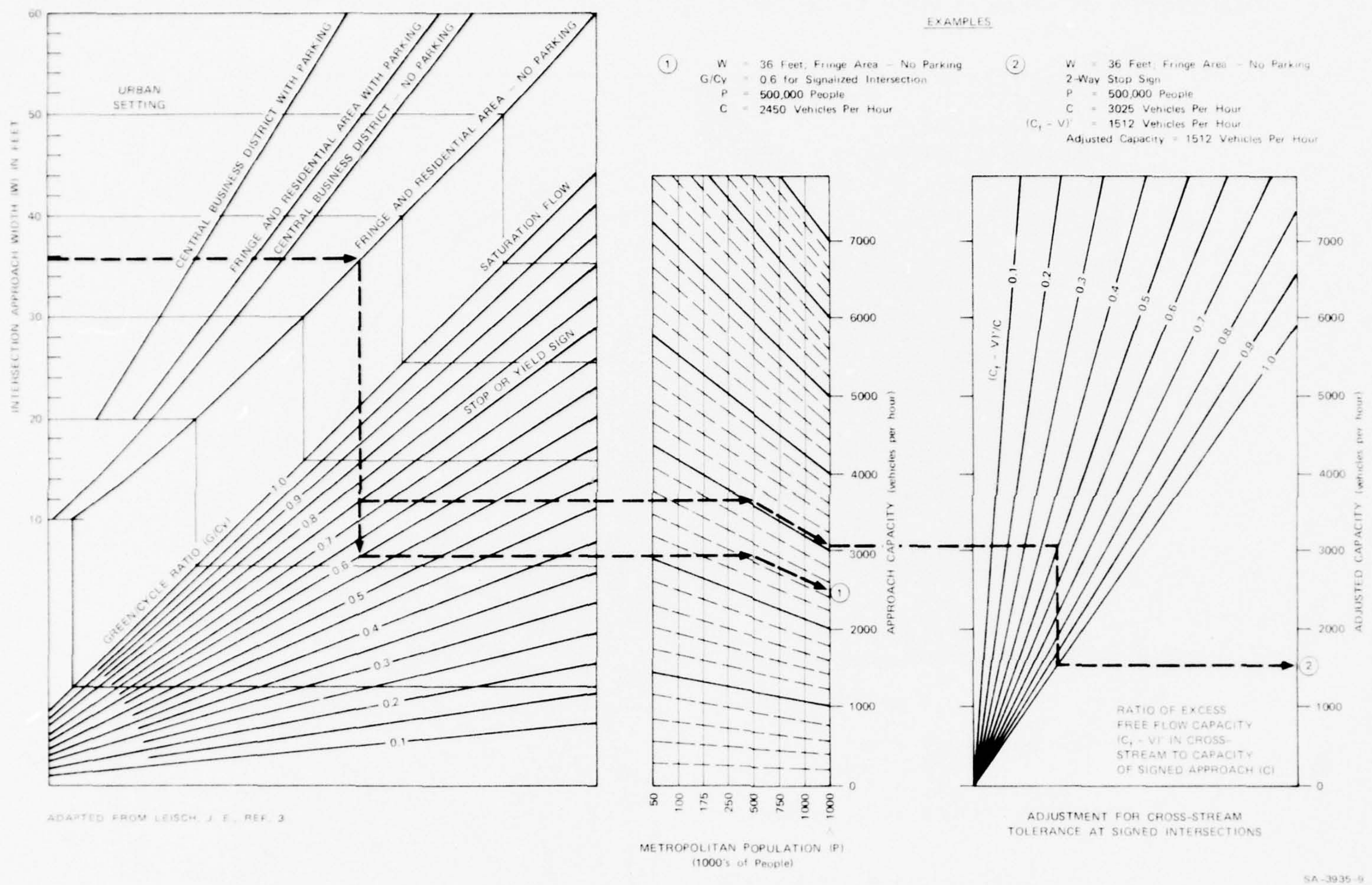


FIGURE A-3 CAPACITY ESTIMATION FOR SIGNED AND SIGNALIZED INTERSECTIONS UNDER MAXIMUM LOAD

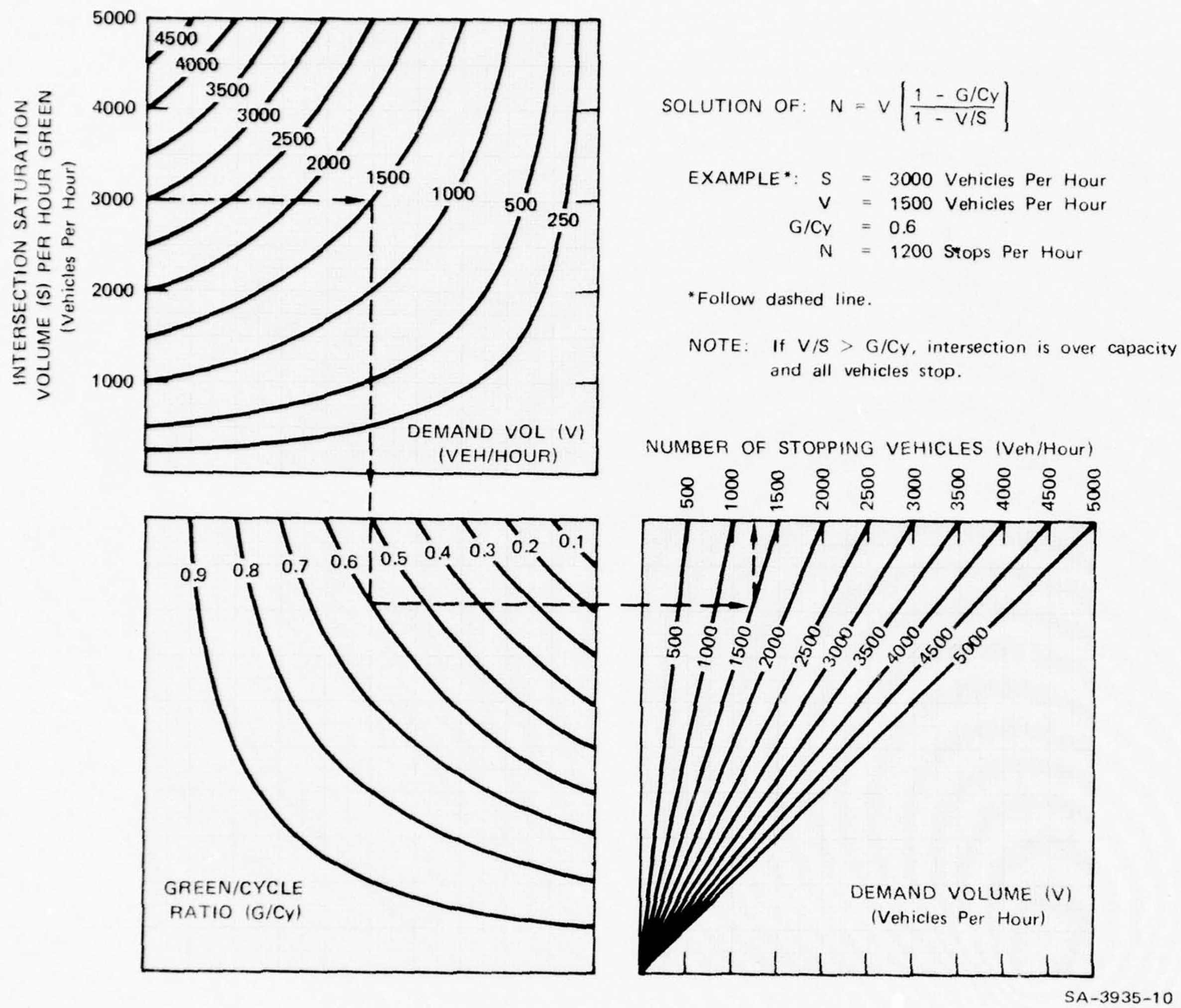
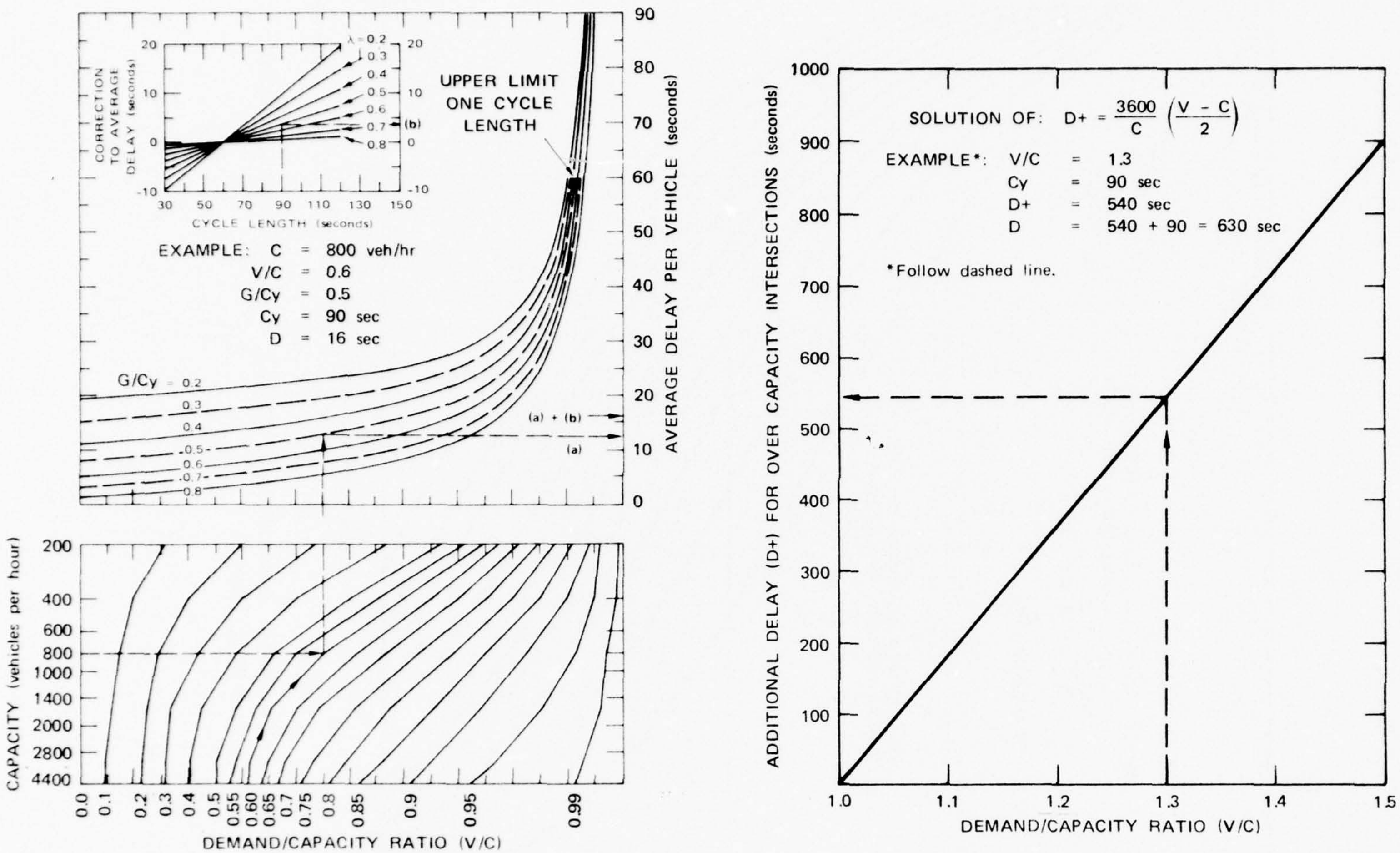


FIGURE A-4 GRAPHICAL ESTIMATION OF THE NUMBER OF VEHICLES PER HOUR STOPPING AT A SIGNALIZED INTERSECTION



(a) UNDER CAPACITY INTERSECTIONS

(b) OVER CAPACITY INTERSECTIONS

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FIGURE A-5 GRAPHICAL ESTIMATION OF DELAY AT SIGNALIZED INTERSECTIONS (ADAPTED FROM FIGURE 16, REF. 2)

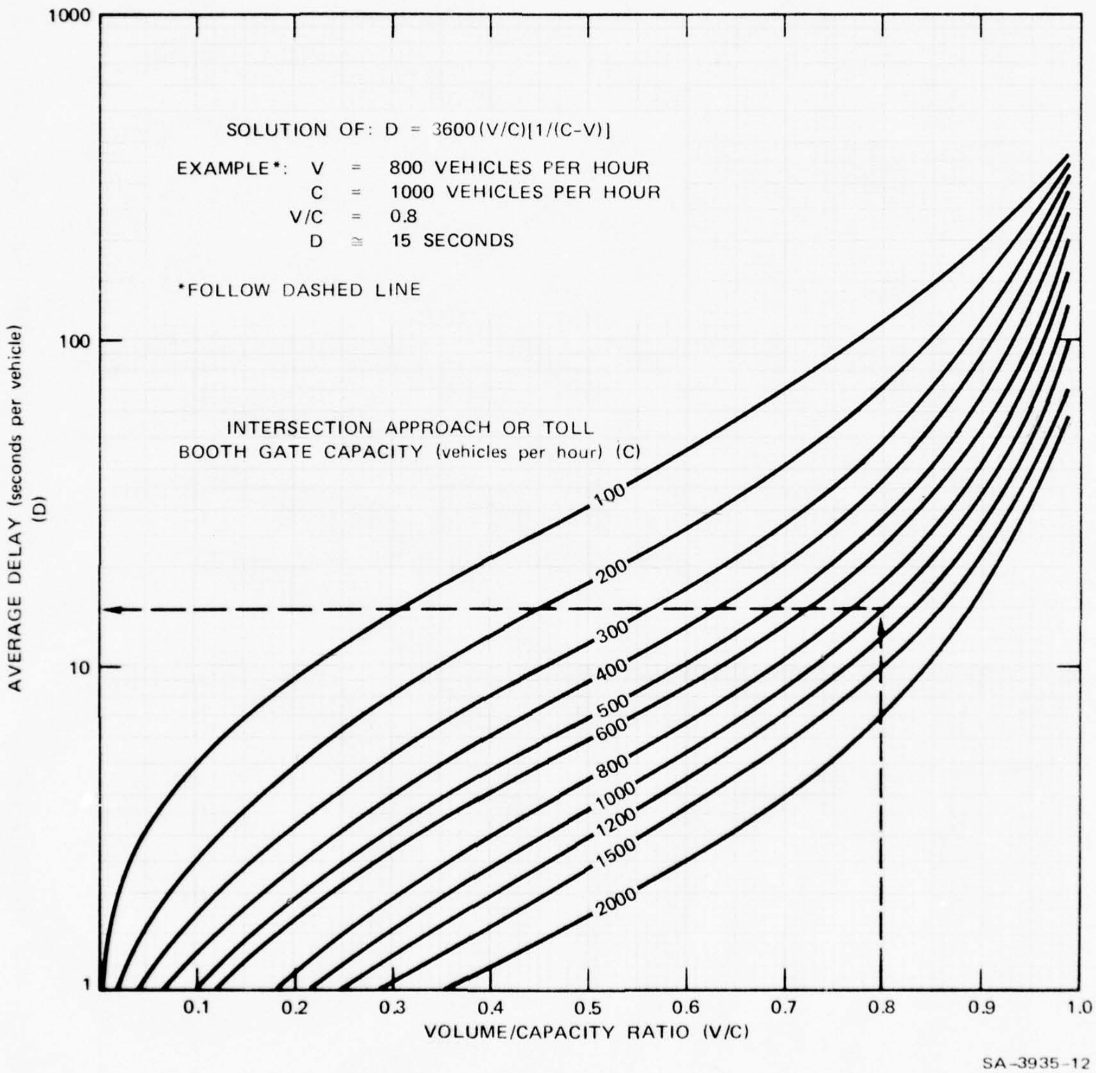

FIGURE A-6 GRAPHICAL ESTIMATION OF DELAY AT SIGNED INTERSECTIONS AND TOLL BOOTHS

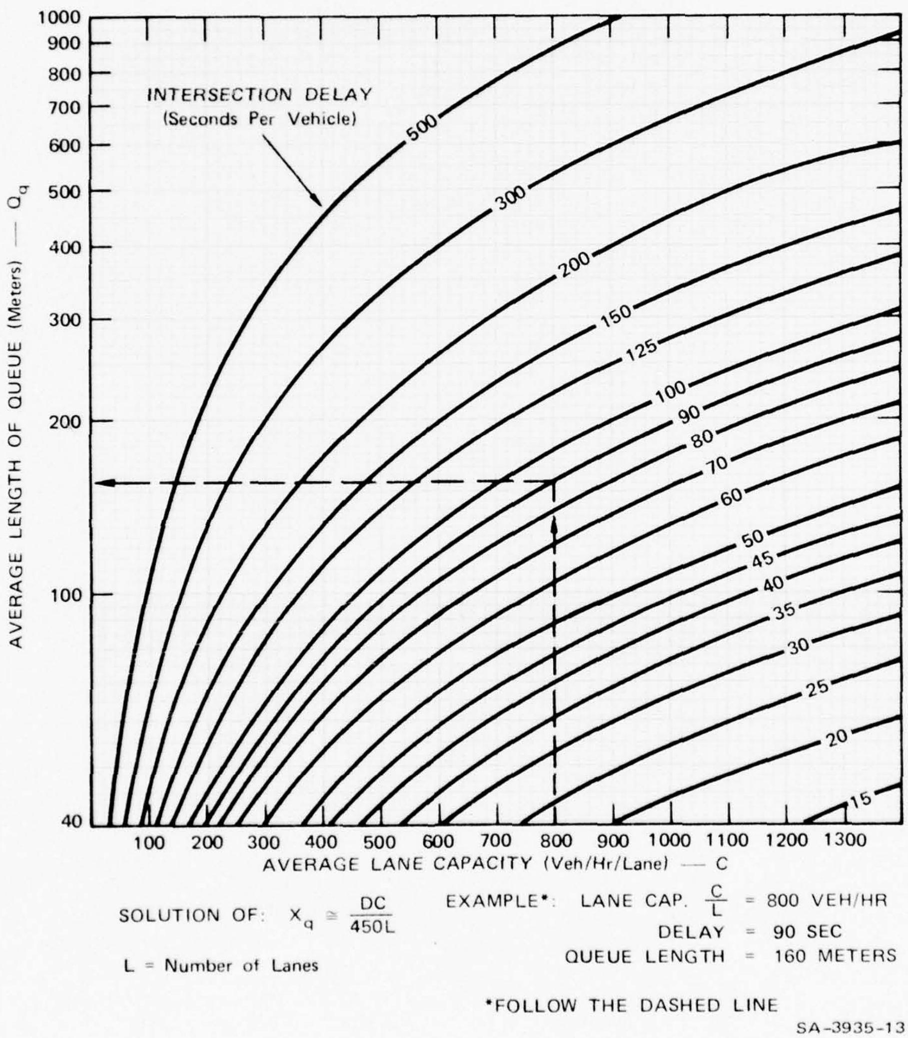

FIGURE A-7 GRAPHICAL ESTIMATION OF QUEUE LENGTH AS A FUNCTION OF LANE CAPACITY AND INTERSECTION DELAY WITH A MINIMUM QUEUE LENGTH OF 40 METERS ASSUMED

Appendix B

NAVY AREA-WIDE TRANSPORTATION STUDY:
DEVELOPMENT OF SCENARIOS FOR EVALUATION

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Appendix B

NAVY AREA-WIDE TRANSPORTATION STUDY: DEVELOPMENT OF SCENARIOS FOR EVALUATION

Using the Navy Area-Wide Transportation Action Plan developed for the Tidewater region in 1975, SRI has outlined several transportation scenarios to test the evaluation methodology described in this report. The scenarios are hypothetical transportation actions meant to address the "what if" situation typically confronting persons facing a decision on the effectiveness of various transportation options in a region. Since the transportation plan outlined for Tidewater was purposely designed to be multimodal, the scenarios describe a mix of complementary actions that might be implemented along a given corridor. Two primary Navy commute corridors were selected for demonstration purposes (Figure B-1): Corridor 1 is the V44/I64 route from Virginia Beach to Sewells Point, which has been broken into two segments for analysis (a close-in segment and a distant segment); (2) Corridor 2 is the developing corridor of Portsmouth to Sewells Point through the Midtown Tunnel. A hypothetical boundary was drawn around grids on the regional map that SRI felt represented (1) Navy commuters actually traveling the corridor and (2) realistic transit market potential for the actions described by the scenarios. For example, an assumption was made that potential vanpoolers would live within at least 4 miles of one another and that potential express bus riders would most likely be those persons living close to the pickup point along the corridor.

The numbers of Navy commuters within each grid cell were identified from the raw data resulting from the Navy's origin-destination survey (1973) and scaled upward by 1.4 to include nonresponses. Modal split was not included in the survey data, so SRI applied a standard modal split reported by the Navy carpool program to each grid cell. The baseline data are depicted in Table B-1 for the two corridors being analyzed.

The following briefly describes each scenario and identifies any assumptions made regarding modal shift. The basic assumptions that apply to all scenarios include: a 47-passenger bus averages 35 passengers (75% capacity); a 15-passenger van will average 12 passengers; and a carpool will average 2 riders plus driver.

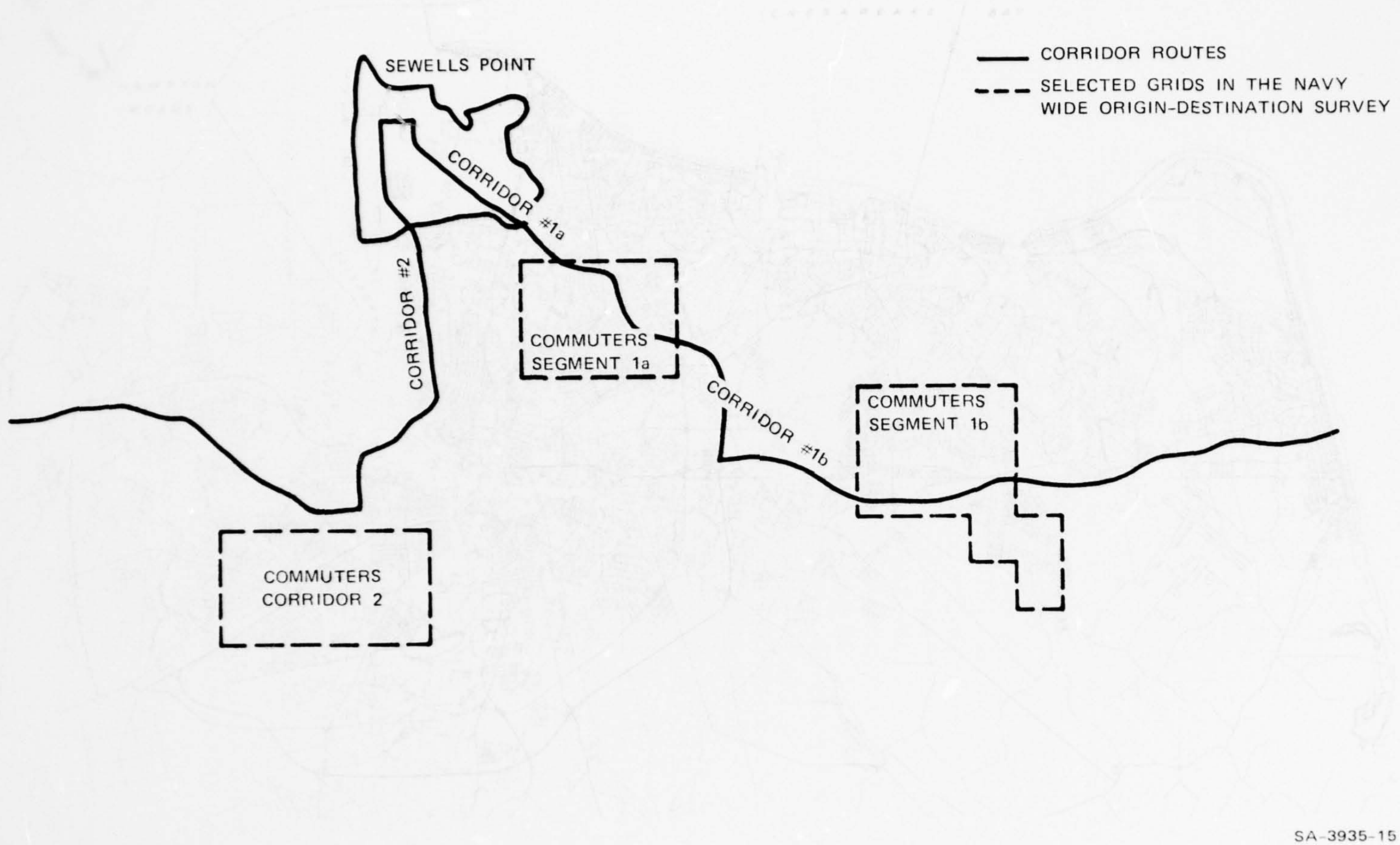

FIGURE B-1 STUDY CORRIDOR ROUTES AND SELECTED RESIDENCE AREAS OF SEWELLS POINT COMMUTERS

Table B-1

BASELINE DATA BY COMMUTE OPTIONS

Corridor	Grids	Total Commuters*	Mode Split: Car 72.3%	Bus 8.4%	Carpool 19.3%
Corridor 1					
Segment 1a	29A	334	241	29	64
	B	397	287	33	77
	C	383	276	33	74
	D	460	332	39	89
	30A	370	267	32	71
	C	316	228	27	61
Subtotal 1a		2,260	1,631	193	436
Segment 1b	44A	368	266	31	71
	B	226	163	19	44
	C	252	182	21	49
	D	130	94	11	25
	45A	176	127	15	34
	C	234	169	20	45
	57A	333	240	29	64
	B	258	186	22	50
	D	213	154	18	41
Subtotal 1b		2,190	1,581	186	423
Total corridors 1a and 1b		4,450	3,212	379	859
Corridor 2	50A	139	100	12	27
	B	102	74	8	20
	C	76	55	6	15
	D	244	176	21	47
	51A	179	129	15	35
	B	189	137	16	36
	C	88	64	7	17
	D	108	78	9	21
Total corridor 2		1,125	813	94	218

*Data scaled up by factor of 1.4 to include nonresponses to original survey.

Source: Navywide origin-destination survey conducted by the Fifth Naval District Headquarters, Energy Coordinator, 1973.

Corridor 1--Segment 1a, Norfolk I64 from Norview Avenue to Sewells Point. Navy commuters from grids #29 and #30.

- Scenario 1 (Corridor 1a)

  - Bus, assume 100% increase in bus patronage:

    193 bus riders x 2 = 386 (11 buses)

    Actions: Intensive corridor marketing program, increased scheduled service

  - Carpool, assume 100% increase in carpoolers:

    436 carpoolers x 2 = 872

    Actions: New matching program, marketing, incentive program on base

  - Vanpool, assume attract 8% of car drivers = 131 commuters (10 vans)

    Action: Implement vanpool program

  - Number of single-occupant vehicles resulting from move to other modes:

    1,631 cars - (193 + 436 + 131) = 871

- Scenario 2 (Corridor 1a)

  - Bus, assume 50% increase in bus patronage:

    193 bus riders x 1.5 = 290 (9 buses)

    Actions: No additional service, optimize existing service through marketing and establish flexible hours for commuters in grids that coordinate with scheduled service

  - Carpool, assume 50% increase in carpoolers:

    436 carpoolers x 1.5 = 654

    Actions: Initiate new matching program, market on base, provide incentives

  - Car, decrease in single-occupant vehicles:

    1,631 cars - (97 + 218) = 1,316

Corridor 1--Segment 1b, V44 and I64 from Rosemont Road to Sewells Point. Navy commuters from grids 44, 45, 57.

- Scenario 1 (Corridor 1b)

  - Bus, decrease in patronage of scheduled bus service, move to express buses:

    126 bus riders - 25 = 101 (3 buses)

  - Carpool, decrease in carpool, move to vanpool:

    423 carpoolers - 127 = 296

  - Vanpool, assume attract 30% of carpoolers (127) and 7% of car drivers (111) = 238 (20 vans)

    Action: Implement vanpool program and market in grids 44, 45, and 57

  - Express bus, assume attract 20% of regular scheduled bus patronage (25) and add to existing 60 riders:

    60 + 25 = 85 (3 buses)

    Action: Market express buses, provide park and ride pickup areas

  - Car, decrease in single-occupant vehicles;

    1,581 cars - 111 = 1,470

- Scenario 2 (Corridor 1b)

  - Bus, assume 100% increase in bus patronage:

    126 bus riders x 2 = 252 (8 buses)

    Action: Intensive corridor marketing program, increased scheduled service

  - Carpool, assume 100% increase in carpooling:

    423 x 2 = 846

    Action: Initiate new matching program, market, provide incentives on base

  - Express bus, service remains the same: 60 (2 buses)

  - Car, decrease in single-occupant vehicles

    1,581 cars - (423 + 126) = 1,032

Corridor 2--Air Line Boulevard to Sewells Point through the Midtown Tunnel. Navy commuters from grids 50 and 51.

- Scenario 1 (Corridor 2)

  - Bus, decrease scheduled bus patronage from move to express buses:

    94 bus riders - 85 = 9 (1 bus)

  - Carpool, remains the same: 218

  - Vanpool, assume attract 8% of car drivers:

    (813 car drivers)(0.08) = 65 (5 vans)

    Action: Implement vanpool program and market

  - Express bus, assume attract 5% of car drivers (41), plus 90% of bus riders (85) = 126 (4 buses)

    Action: Implement and market express bus service, provide shuttle service to park and ride lot

  - Car, decrease in single-occupant vehicles:

    813 cars - (65 + 41) = 707

- Scenario 2 (Corridor 2)

  - Bus, assume 100% increase in bus patronage:

    94 bus riders x 2 = 188 (6 buses)

    Action: Intensive corridor marketing program, increase scheduled service if necessary

  - Carpool, assume 100% increase in carpooling:

    218 carpoolers x 2 = 436

    Action: Initiate new matching program, market on base, provide additional incentives on base

  - Car, decrease in single-occupant vehicles:

    813 cars - (94 + 218) = 501

Table B-2 summarizes the modal shifts assumed for each of the above scenarios. These data, translated into vehicle miles traveled and traffic flow characteristics, were the primary input to the algorithms for evaluating air quality and energy consumption effects of transportation alternatives. Other criteria such as land use and costs were calculated separately as they apply to each scenario described.

Table B-2

SUMMARY OF MODAL SHIFTS FOR EACH SCENARIO

	Baseline	Scenario 1	Scenario 2
Corridor 1--Segment 1a			
Bus	193	386	290
Carpool	436	872	654
Vanpool		131	
Express bus			
Car	1,631	871	1,316
Total commuters 1a	2,260	2,260	2,260
Corridor 1--Segment 1b			
Bus	126	101	252
Carpool	423	296	846
Vanpool		238	
Express bus	60	85	60
Car	1,581	1,470	1,032
Total commuters 1b	2,190	2,190	2,190
Corridor 1--Segment 1a and 1b combined			
Bus	319	487	542
Carpool	859	1,168	1,500
Vanpool		369	
Express bus	60	85	60
Car	3,212	2,341	2,348
Total commuters 1a and 1b	4,450	4,450	4,450
Corridor 2			
Bus	94	9	188
Carpool	218	218	436
Vanpool		65	
Express bus		126	
Car	813	707	501
Total commuters 2	1,125	1,125	1,125

Appendix C

TIDEWATER DEMONSTRATION DATA

PART I

MANUAL DATA

Data Sheet 1

PRIMARY INPUT INFORMATION
(STUDY HOUR)
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Link Demand Volume (vehicles per hour)	Link Length (miles and tenths)	Vehicle Miles Traveled	Operating Speed (miles per hour)	Stopping Rate (vehicles per hour)	Intersection Delay (seconds)	Average Queue Length (meters)
2	681	1.2	817	40	--	--	--
4	681	0.3	204	40	--	--	--
6	872	0.8	698	40	497	10	<40
8	1356	1.3	1763	40	0	0	--
10	1356	0.9	1220	35	922	12	<40
12	707	0.3	212	40	361	8	<40
14	1186	0.2	237	40	--	--	--
16	1186	0.4	479	40	--	--	--
18	972	0.8	778	55	--	--	--
20	972	0.5	486	55	--	--	--
22	972	0.3	292	55	972	6	<40
24	972	0.7	680	25	--	--	--
26	972	0.2	194	25	972	10	<40
28	1368	0.3	410	25	1163	18	<40
30	1492	0.7	1044	25	1194	14	<40
32	1616	0.2	323	25	1438	20	<40
34	1598	1.2	959	25	1119	12	<40
36	1798	1.1	1978	25	--	--	--
38	1798	0.2	360	25	1384	12	<40
40	2076	0.2	415	25	1124	12	<40
42	2206	0.7	1544	25	--	--	--
44	1928	1.3	2506	25	1581	14	<40
46	411	0.8	329	25	345	20	<40

Data Sheet 1

PRIMARY INPUT INFORMATION
(STUDY HOUR)
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Link Demand Volume (vehicles per hour)	Link Length (miles and tenths)	Vehicle Miles Traveled	Operating Speed (miles per hour)	Stopping Rate (vehicles per hour)	Intersection Delay (seconds)	Average Queue Length (meters)
48	2363	0.4	945	30	N/A	N/A	N/A
50	2363	1.6	3781	30			
52	2363	0.8	1890	30			
54	1600	0.4	640	30			
56	1600	0.2	320	30			
58	3120	0.9	2808	42			
60	3720	0.3	1116	36			
62	3720	0.6	2232	36			
64	4230	0.2	846	34			
66	4230	0.7	2961	34			
68	4230	0.4	1692	34			
70	4230	0.8	3384	34			
72	4230	0.8	3384	34			
74	4230	0.2	846	34			
76	4230	2.1	8862	34			
78	3362	0.8	2690	35			
80	3362	0.7	2353	35			
82	3362	0.8	2690	35			
84	3461	0.8	2769	33			
86	3461	0.5	1730	33			
88	1959	1.1	2155	43			
90	1959	1.2	2351	43			
92	1800	0.5	900	45			
94	1800	0.8	1440	45			
96	1800	0.4	720	45			
98	1216	1.2	1459	47			
100	813	2.0	1626	50			
102	813	0.9	732	50			
104	503	1.2	604	53			

Data Sheet 2

NETWORK FUEL CONSUMPTION ESTIMATION
(STUDY HOUR)
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Cruise Mode Consumption (gallons)	Delay Mode Consumption (gallons)		Total Consumption (gallons)
		Idle	Speed change	
(1)	(2)	(3)	(4)	(5)
2	38.4	--	--	38.4
4	9.6	--	--	9.6
6	32.2	1.6	6.5	40.3
8	82.9	--	--	82.9
10	54.3	2.8	10.3	67.1
12	12.1	1.0	3.4	16.5
14	11.1	--	--	11.1
16	22.3	--	--	22.3
18	41.2	--	--	41.2
20	25.8	--	--	25.8
22	15.5	0.9	18.1	34.5
24	34.0	--	--	34.0
26	9.7	2.7	13.0	25.4
28	20.5	4.6	11.6	36.7
30	52.2	3.9	12.6	68.7
32	16.2	5.7	14.0	35.9
34	48.0	3.3	9.0	60.3
36	98.9	--	--	98.9
38	18.0	3.8	11.4	33.2
40	20.8	4.4	9.5	34.7
42	77.2	--	--	77.2
44	125.3	4.6	13.4	143.3
46	16.4	1.4	2.9	16.4

Data Sheet 2

NETWORK FUEL CONSUMPTION ESTIMATION
(STUDY HOUR)
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Cruise Mode Consumption (gallons)	Delay Mode Consumption (gallons)		Total Consumption (gallons)
		Idle	Speed Change	
48	45.4	N/A	N/A	45.4
50	181.5			181.5
52	90.7			90.7
54	30.7			30.7
56	15.4			15.4
58	134.8			134.8
60	53.6			53.6
62	107.1			107.1
64	40.6			40.6
66	142.1			142.1
68	81.2			81.2
70	162.4			162.4
72	162.4			162.4
74	40.6			40.6
76	425.4			425.4
78	129.1			129.1
80	112.9			112.9
82	129.1			129.1
84	132.9			132.9
86	83.0			83.0
88	103.4			103.4
90	112.8			112.8
92	44.1			44.1
94	70.6			70.6
96	35.3			35.3
98	72.9			72.9
100	82.9			82.9
102	37.3			37.3
104	32.0			32.0

Data Sheet 3

NETWORK POLLUTANT EMISSION ESTIMATION
(STUDY HOUR)
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Carbon Monoxide Emissions			Total CO Emissions (kilograms)	Hydrocarbon Emissions			Total HC Emissions (kilograms)
	Cruise Mode Emissions	Delay Mode Emissions (kilograms)			Cruise Mode Emissions	Delay Mode Emissions (kilograms)		
		Idle	Speed Change			Idle	Speed Change	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2	18.8	--	--	18.8	1.6	--	--	1.6
4	4.7	--	--	4.7	0.4	--	--	0.4
6	16.0	1.2	4.3	21.5	1.3	0.1	0.4	1.8
8	40.5	--	--	40.5	3.4	--	--	3.4
10	30.5	2.8	6.7	40.0	2.5	0.2	0.6	3.3
12	4.9	2.2	3.1	10.2	0.4	0.2	0.2	0.8
14	5.4	--	--	5.4	0.4	--	--	0.4
16	10.9	--	--	10.9	0.9	--	--	0.9
18	15.6	--	--	15.6	1.3	--	--	1.3
20	9.7	--	--	9.7	0.8	--	--	0.8
22	5.8	1.2	12.6	19.4	0.5	0.1	1.0	1.6
24	20.4	--	--	20.4	1.7	--	--	1.7
26	5.8	2.6	8.0	16.4	0.5	0.2	0.7	1.4
28	12.3	5.3	6.5	24.1	1.0	0.4	0.5	2.0
30	31.3	2.6	7.2	41.1	2.6	0.2	0.6	3.4
32	9.7	7.4	7.8	24.9	0.8	0.6	0.6	2.1
34	28.8	3.4	5.4	37.6	2.4	0.3	0.4	3.1
36	59.3	--	--	59.3	4.9	--	--	4.9
38	10.8	4.2	6.5	21.5	0.9	0.3	0.5	1.8
40	12.4	5.2	5.4	23.0	1.0	0.4	0.4	1.9
42	46.3	--	--	46.3	3.8	--	--	3.9
44	75.2	3.5	7.6	86.3	6.3	0.3	0.6	7.2
46	9.9	1.8	2.6	14.3	0.8	0.1	0.2	1.2

Data Sheet 3

NETWORK POLLUTANT EMISSION ESTIMATION
(STUDY HOUR)
(Inbound Links, 7-8 A.M.)

Link I.D. No. (1)	Carbon Monoxide Emissions			Total CO Emissions (kilograms) (5)	Hydrocarbon Emissions			Total HC Emissions (kilograms) (9)
	Cruise Mode Emissions (2)	Delay Mode Emissions (kilograms)			Cruise Mode Emissions (6)	Delay Mode Emissions (kilograms)		
		Idle (3)	Speed Change (4)			Idle (7)	Speed Change (8)	
48	25.5	N/A	N/A	25.5	2.1	N/A	N/A	2.1
50	102.1			102.1	8.5			8.5
52	51.0			51.0	4.2			4.2
54	17.3			17.3	1.4			1.4
56	8.6			8.6	0.7			0.7
58	61.6			61.6	5.1			5.1
60	26.8			26.8	2.2			2.2
62	53.6			53.6	4.5			4.5
64	21.1			21.1	1.8			1.8
66	74.0			74.0	6.2			6.2
68	42.3			42.3	3.5			3.5
70	84.6			84.6	7.0			7.0
72	84.6			84.6	7.0			7.0
74	21.2			21.2	1.8			1.8
76	221.6			221.6	18.5			18.5
78	67.2			67.2	5.6			5.6
80	58.8			58.8	4.9			4.9
82	67.2			67.2	5.6			5.6
84	69.2			69.2	5.8			5.8
86	43.2			43.2	3.6			3.6
88	47.4			47.4	3.9			3.9
90	51.7			51.7	4.3			4.3
92	18.9			18.9	1.6			1.6
94	30.2			30.2	2.5			2.5
96	15.1			15.1	1.2			1.2
98	30.6			30.6	2.5			2.5
100	32.5			32.5	2.7			2.7
102	14.6			14.6	1.2			1.2
104	12.1			12.1	1.0			1.0

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A METHODOLOGY FOR MAKING A QUANTITATIVE ASSESSMENT OF PASSENGER--ETC(U)
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Data Sheet 4

LOCAL CARBON MONOXIDE CONCENTRATION ESTIMATION
(STUDY HOUR)
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Worst Case Background Concentration (milligrams per cubic meter)	Link Contribution					Total Impact (milligrams/cubic meter)	
		Emission Density (grams per meter per second)			1-Hour Concentration (milligrams/cubic meter)			
		Cruise	Delay	Total	Mid-Block	Inter-section	Mid-Block	Inter-section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2	3.0	.0027	--	.0027	0.4	--	3.4	--
4	3.0	.0027	--	.0027	0.4	--	3.4	--
6	3.0	.0034	.0352	.0386	0.5	5.6	3.5	8.6
8	3.0	.0054	--	.0054	0.5	--	3.5	--
10	3.0	.0058	.0564	.0622	0.8	9.0	3.8	12.0
12	3.0	.0028	.0340	.0368	0.4	5.3	3.4	8.3
14	3.0	.0046	--	.0046	0.7	--	3.7	--
16	3.0	.0047	--	.0047	0.7	--	3.7	--
18	3.0	.0034	--	.0034	0.5	--	3.5	--
20	3.0	.0033	--	.0033	0.5	--	3.5	--
22	3.0	.0033	.0724	.0757	0.5	11.0	3.5	14.0
24	3.0	.0050	--	.0050	0.7	--	3.7	--
26	3.0	.0050	.0610	.0660	0.7	9.6	3.7	12.6
28	3.0	.0071	.0737	.0808	1.0	11.7	4.0	14.7
30	3.0	.0077	.0566	.0643	1.1	9.3	4.1	12.3
32	3.0	.0084	.0970	.1054	1.2	15.3	4.2	18.3
34	3.0	.0083	.0544	.0627	1.2	9.1	4.2	12.1
36	3.0	.0093	--	.0093	1.3	--	4.3	--
38	3.0	.0093	.0660	.0753	1.3	10.9	4.3	13.9
40	3.0	.0107	.0684	.0791	1.6	11.4	4.6	14.4
42	3.0	.0114	--	.0114	1.6	--	4.6	--
44	3.0	.0100	.0686	.0786	1.4	11.4	4.4	14.4
35	3.0	.0021	.0306	.0327	0.3	4.7	3.3	7.7

Data Sheet 4

LOCAL CARBON MONOXIDE CONCENTRATION ESTIMATION
(STUDY HOUR)
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Worst Case Background Concentration (milligrams per cubic meter)	Link Concentration					Total Impact (milligrams/cubic meter)	
		Emission Density (grams per meter per second)			1-Hour Concentration (miligrams/cubic meter)			
		Cruise	Delay	Total	Mid-Block	Inter-section	Mid-Block	Inter-section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
48	3.0	.0110	N/A	.0110	1.6	N/A	4.6	N/A
50	3.0	.0110		.0110	1.6		4.6	
52	3.0	.0110		.0110	1.6		4.6	
54	3.0	.0075		.0075	1.1		4.1	
56	3.0	.0074		.0074	1.1		4.1	
58	3.0	.0118		.0118	1.7		4.7	
60	3.0	.0154		.0154	2.2		6.2	
62	3.0	.0154		.0154	2.2		6.2	
64	3.0	.0182		.0182	2.6		6.6	
66	3.0	.0182		.0182	2.6		6.6	
68	3.0	.0182		.0182	2.6		6.6	
70	3.0	.0182		.0182	2.6		6.6	
72	3.0	.0182		.0182	2.6		6.6	
74	3.0	.0182		.0182	2.6		6.6	
76	3.0	.0182		.0182	2.6		6.6	
78	3.0	.0145		.0145	2.1		6.1	
80	3.0	.0145		.0145	2.1		6.1	
82	3.0	.0145		.0145	2.1		6.1	
84	3.0	.0145		.0145	2.1		6.1	
86	3.0	.0145		.0145	2.1		6.1	
88	3.0	.0145		.0145	2.1		6.1	
90	3.0	.0145		.0145	2.1		6.1	
92	3.0	.0065		.0065	0.9		4.9	
94	3.0	.0065		.0065	0.9		4.9	
96	3.0	.0065		.0065	0.9		4.9	
98	3.0	.0044		.0044	0.6		4.6	
100	3.0	.0028		.0028	0.4		4.4	
102	3.0	.0012		.0012	0.2		4.2	
104	3.0	.0010		.0010	0.1		4.1	

Data Sheet 5

COMMUTER COST ESTIMATION

Commute Corridor		Establish Average Mileage for Aggregate Link (3)	Average Cost per Mile by Mode (4)				Annual Commuter Costs by Mode of Travel (5)			
Link I.D. No. (1)	Aggregate Commute Links (2)		Single-Occupant Car	Carpool	Vanpool	Bus	Single-Occupant Car	Carpool	Vanpool	Bus
Links: (45-46)-(65-66	1a	5.8	m 10.3 f 18.9	3.4 6.3	.05	.55	285.60 526.18	95.20 175.39	139.20	264.00
Links: (45-46)-(89-90)	1b	16.8	m 10.3 f 18.9	3.4 6.3	.05	.65	950.40 1644.00	316.80 548.00	403.20	312.00
Links: (13-14)-(45-46)	2	9.2	m 10.3 f 18.9	3.4 6.3	.05	.60	576.00 955.20	192.00 318.40	220.80	288.00

Data Sheet 6

LAND USE RELATIONSHIPS

Commute Corridor Market Area (1)	Existing Land Use (acres) (2)					Parking Area Required by Mode of Travel at Work Location (3)			
	Residential	Commercial	Industrial	Undeveloped (open space)	Right-of-Way for Corridor	Auto	Carpool	Vanpool	Bus

Data for this demonstration not completed.

Data Sheet 7

COMPILATION OF PER-VEHICLE FUEL CONSUMPTION AND POLLUTANT EMISSION FACTORS
(STUDY HOUR)
(Inbound Links, 7-8 A.M.)

Link I.D. No. (1)	Link Demand Volume (vehicles per hour) (2)	Link Fuel Consumption per 100 Vehicles (gallons) (3)	Link Pollutant Emission per 100 Vehicles (kilograms)		Cumulative Fuel Consumption and Pollutant Emissions per 100 Vehicles		
			Carbon Monoxide (4)	Hydrocarbons (5)	Fuel (gallons) (6)	Carbon Monoxide (kilograms) (7)	Hydrocarbons (kilograms) (8)
46	411	4.0	3.5	0.3	4.0	3.5	0.3
44	1928	7.4	4.5	0.3	11.4	8.0	0.7
42	2206	3.5	2.1	0.2	14.9	10.1	0.9
40	2076	1.7	1.1	0.1	16.6	11.2	1.0
38	1798	1.8	1.2	0.1	18.4	12.4	1.1
36	1798	5.5	3.3	0.3	23.9	15.7	1.4
34	1598	3.8	2.4	0.2	27.7	18.1	1.6
32	1616	2.2	1.5	0.1	29.9	19.6	1.7
30	1492	4.6	2.8	0.2	34.5	22.4	1.9
28	1368	2.7	1.8	0.1	36.2	24.2	2.0
26	972	2.6	1.7	0.1	38.8	25.9	2.1
24	972	3.5	2.1	0.2	42.3	28.0	2.2
22	972	3.5	2.0	0.2	45.8	30.0	2.4
20	972	2.7	1.0	0.1	48.5	31.0	2.5
18	972	4.2	1.6	0.1	52.7	32.6	2.6
16	1186	1.9	0.9	0.1	54.6	33.5	2.7
14	1186	0.9	0.4	0.1	55.5	33.9	2.8
12	707	2.3	1.4	0.1	57.8	35.3	2.9
10	1356	4.9	3.0	0.2	62.7	38.3	3.1
8	1356	6.1	3.0	0.2	68.8	41.3	3.3
6	872	4.6	2.5	0.2	73.4	43.8	3.6
4	681	1.4	0.7	0.1	74.8	44.5	3.6
2	681	5.6	2.8	0.2	80.4	47.3	3.8

Data Sheet 7

COMPILATION OF PER-VEHICLE FUEL CONSUMPTION AND POLLUTANT EMISSION FACTORS
(STUDY HOUR)
(Inbound Links, 7-8 A.M.)

Link I.D. No. (1)	Link Demand Volume (vehicles per hour) (2)	Link Fuel Consumption per 100 Vehicles (gallons) (3)	Link Pollutant Emission per 100 Vehicles (kilograms)		Cumulative Fuel Consumption and Pollutant Emissions per 100 Vehicles		
			Carbon Monoxide (4)	Hydrocarbons (5)	Fuel (gallons) (6)	Carbon Monoxide (kilograms) (7)	Hydrocarbons (kilograms) (8)
48	2363	1.9	1.1	0.1	--*	--	--
50	2363	7.7	4.3	0.4	--	--	--
52	2363	3.8	2.2	0.2	--	--	--
54	1600	1.9	1.1	0.1	--	--	--
56	1600	0.9	0.5	0.1	10.1	4.6	0.4
58	3120	4.3	2.0	0.2	14.4	6.6	0.6
60	3720	1.4	0.7	0.1	15.8	7.3	0.7
62	3720	2.9	o.4	0.1	18.7	8.7	0.8
64	4230	1.0	0.5	0.1	19.7	9.2	0.9
55	4230	3.4	1.7	0.1	23.1	10.9	1.0
68	4230	1.9	1.0	0.1	25.0	11.9	1.1
70	4230	3.8	2.0	0.2	28.8	13.9	1.3
72	4230	3.8	2.0	0.2	31.9	15.9	1.5
74	4230	1.0	0.5	0.1	32.9	16.4	1.6
76	4230	8.1	4.2	0.4	41.0	20.6	2.0
78	3362	3.8	2.0	0.2	44.8	22.6	2.2
80	3362	3.4	1.8	0.2	48.2	24.4	2.4
82	3362	3.8	2.0	0.2	52.0	26.4	2.6
84	3461	3.8	2.0	0.2	55.8	28.4	2.8
86	3461	2.4	1.2	0.1	58.2	29.6	2.9
88	1959	5.3	2.4	0.2	63.5	32.0	3.1
90	1959	5.8	3.2	0.3	69.3	35.2	3.4
92	1800	2.4	1.0	0.1	71.7	36.2	3.5
94	1800	3.9	1.7	0.1	75.6	37.9	3.6
96	1800	2.0	0.8	0.1	77.6	38.7	3.7
98	1216	6.0	2.5	0.2	83.6	41.2	3.9
100	813	10.2	4.0	0.3	93.8	45.2	4.2
102	813	4.6	1.8	0.2	98.4	47.0	4.4
104	503	6.4	2.4	0.2	104.8	49.4	4.6

*It was considered unlikely that commuters would enter the corridor in these links.

Worksheet A-1

ESTIMATION OF LINK CRUISE SPEED

Link I.D. No.	Study Hour Demand Volume (vehicles per hour) (1)	Free Flow Capacity (vehicles per hour) (2)	Demand/Capacity Ratio [(1)÷(2)]	Cruise Speed (miles per hour) (3)
2				40
4				40
6				40
8				40
10				46
12				40
14				40
16				40
18				55
20				55
22				55
24				25
26				25
28				25
30				25
32				25
34				25
36				25
38				25
40				25
42				25
44				25
46				25

For convenience, posted speeds were used in Portsmouth and a flat 25 mph in Norfolk as the basis for our demonstration.

Worksheet A-1

ESTIMATION OF LINK CRUISE SPEED

Link I.D. No.	Study Hour Demand Volume (vehicles per hour) (1)	Free Flow Capacity (vehicles per hour) (2)	Demand/Capacity Ratio [(1):(2)]	Cruise Speed (miles per hour) (3)
48				25
50	Posted and observed speed			25
52	information was used here			25
54				30
56				30
58	3120	5700	.55	42
60	3720	5700	.65	36
62	3720	5700	.65	36
64	4230	5700	.74	34
66	4230	5700	.74	34
68	4230	5700	.74	34
70	4230	5700	.74	34
72	4230	5700	.74	34
74	4230	5700	.74	34
76	4230	5700	.74	34
78	3362	4000	.84	35
80	3362	4000	.84	35
82	3362	4000	.84	35
84	3461	4000	.86	33
86	3461	4000	.86	33
88	1959	4000	.49	43
90	1959	4000	.49	43
92	1800	4000	.45	45
94	1800	4000	.45	45
96	1800	4000	.45	45
98	1216	4000	.30	47
100	813	4000	.20	50
102	813	4000	.20	50
104	503	4000	.12	53

Worksheet A-2

ESTIMATION OF INTERSECTION DELAY
PART I
INTERSECTION CAPACITY
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Type of Control (1)	Approach Width (feet) (2)	Metropolitan Population (3)	Urban Location (4)	Cycle Length (seconds) (5)	Green/Cycle Ratio (6)	Saturation Service Volume (veh/hour) (7)	Intersection Capacity (veh/hour) (8)
2	None	--	500,000	Fringe	--	--	--	--
4	None	--			--	--	--	--
6	Signal	24			90	0.6	2917	1750
8	None	--			--	--	--	--
10	Signal	36			90	0.6	3333	2000
12	Signal	36			90	0.6	4167	2500
14	None	--			--	--	--	--
16	None	--			--	--	--	--
18	None	--			--	--	--	--
20	None	--			--	--	--	--
22	Toll booth	30			--	0.6	3437	2062
24	None	--			--	--	--	--
26	Yield	30			--	0.6	3170	1902
28	Signal	22			90	0.6	2583	1550
30	Signal	26			90	0.6	3000	1800
32	Signal	25			90	0.6	2917	1750
34	Signal	33			90	0.6	3750	2250
36	None	--			--	--	--	--
38	Signal	33			90	0.6	3750	2250
40	Signal	33			90	0.6	3750	2250
42	None	--			--	--	--	--
44	Signal	33			90	0.6	3750	2250
46	None	--			--	--	--	--

Worksheet A-2

ESTIMATION OF INTERSECTION DELAY
PART II
CHARACTERISTICS OF INTERSECTION DELAY
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Demand Volume (veh/hour) (9)	Demand/ Saturation Ratio (9):(7)	Stopping Rate (veh/hour) (10)	Intersection Delay (seconds) (11)	Queue Length (meters) (12)
2	681	--	--	--	--
4	681	--	--	--	--
6	872	0.30	497	10	<40
8	1356	--	--	--	--
10	1356	0.41	909	12	<40
12	707	0.17	594	20	<40
14	1186	--	--	--	--
16	1186	--	--	--	--
18	972	--	--	--	--
20	972	--	--	--	--
22	972	0.28	972	5	<40
24	972	--	--	---	--
26	972	0.31	972	2	<40
28	1368	0.53	1163	18	<40
30	1492	0.50	1194	14	<40
32	1616	0.55	1438	25	<40
34	1598	0.43	1119	12	<40
36	1798	--	--	--	--
38	1798	0.50	1384	12	<40
40	2076	0.55	1124	22	<40
42	2206	--	--	--	--
44	1928	0.51	1581	14	<40
46	411	--	--	--	--

Worksheet A-2

ESTIMATION OF INTERSECTION DELAY
PART I
INTERSECTION CAPACITY
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Type of Control (1)	Approach Width (feet) (2)	Metropolitan Population (3)	Urban Location (4)	Cycle Length (seconds) (5)	Green/Cycle Ratio (6)	Saturation Service Volume (veh/hour) (7)	Intersection Capacity (veh/hour) (8)
48	None	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50								
52								
54								
56								
58								
60								
62								
64								
66								
68								
70								
72								
74								
76								
78								
80								
82								
84								
86								
88								
90								
92								
94								
96								
98								
100								
102								
104								

Worksheet A-2

ESTIMATION OF INTERSECTION DELAY
PART II
CHARACTERISTICS OF INTERSECTION DELAY
(Inbound Links, 7-8 A.M.)

Link I.D. No.	Demand Volume (veh/hour) (9)	Demand/ Saturation Ratio (9):(7)	Stopping Rate (veh/hour) (10)	Intersection Delay (seconds) (11)	Queue Length (meters) (12)
48	N/A	N/A	N/A	N/A	N/A
50					
52					
54					
56					
58					
60					
62					
64					
66					
68					
70					
72					
74					
76					
78					
80					
82					
84					
86					
88					
90					
92					
94					
96					
98					
100					
102					
104					

PART II

AUTOMATED DATA

EXAMPLE OUTPUT DATA FROM NAFCOM

```
                   N-APPR DELAY QUEUE    E-APPR DELAY QUEUE    S-APPR DELAY QUEUE    W-APPR DELAY QUEUE
INTERSECTION   1        0.      0.            0.      0.            0.      0.            0.      0.
INTERSECTION   2        0.      0.            0.      0.            0.      0.            0.      0.

INTERSECTION   3
                  PHASE 1                 PHASE 2                 PHASE 3                 PHASE 4
TIME                33.                     57.                     -0.                     -0.
V/GC              0.00000                 .29883                  0.00000                 0.00000
          NORTH-APPR SOUTH-APPR   EAST-APPR WEST-APPR   N-APP-LEFT S-APP-LEFT   E-APP-LEFT W-APP-LEFT
DELA           0.        0.           9.       10.           0.        0.           9.       10.
QUEUE          0.        0.           0.        0.           0.        0.           0.        0.
VOLUME         0.        0.         689.      872.           0.        0.           0.        0.
CAPACITY       1.        1.        1750.     1751.           0.        0.           0.        0.
V/GCAP   0.00000   0.00000       .23625    .29883      0.00000   0.00000      0.00000   0.00000

INTERSECTION   4
                  PHASE 1                 PHASE 2                 PHASE 3                 PHASE 4
TIME                33.                     57.                     -0.                     -0.
V/GC              0.00000                 .40693                  0.00000                 0.00000
          NORTH-APPR SOUTH-APPR   EAST-APPR WEST-APPR   N-APP-LEFT S-APP-LEFT   E-APP-LEFT W-APP-LEFT
DELA           0.        0.           7.       12.           0.        0.           7.       12.
QUEUE          0.        0.           0.        1.           0.        0.           0.        0.
VOLUME         0.        0.         295.     1356.           0.        0.           0.        0.
CAPACITY       1.        1.        1997.     1999.           0.        0.           0.        0.
V/GCAP   0.00000   0.00000       .08862    .40693      0.00000   0.00000      0.00000   0.00000

INTERSECTION   5
                  PHASE 1                 PHASE 2                 PHASE 3                 PHASE 4
TIME                53.                     37.                     -0.                     -0.
V/GC              .09663                  .15426                  0.00000                 0.00000
          NORTH-APPR SOUTH-APPR   EAST-APPR WEST-APPR   N-APP-LEFT S-APP-LEFT   E-APP-LEFT W-APP-LEFT
DELA           9.        0.           0.       19.           9.        0.           0.       19.
QUEUE          0.        0.           0.        0.           0.        0.           0.        0.
VOLUME       443.        0.           0.      707.           0.        0.           0.        0.
CAPACITY    2547.        1.           1.     1731.           0.        0.           0.        0.
V/GCAP    .09663   0.00000      0.00000    .15426      0.00000   0.00000      0.00000   0.00000

                   N-APPR DELAY QUEUE    E-APPR DELAY QUEUE    S-APPR DELAY QUEUE    W-APPR DELAY QUEUE
INTERSECTION   6        0.      0.            0.      0.            0.      0.            0.      0.
INTERSECTION   7        0.      0.            0.      0.            0.      0.            0.      0.
INTERSECTION   8        3.      1.            0.      0.            7.      1.            0.      0.
INTERSECTION   9        3.      1.            0.      0.            0.      0.            1.      1.
```

INTERSECTION 10

	NORTH-APPR	SOUTH-APPR	EAST-APPR	WEST-APPR	N-APP-LEFT	S-APP-LEFT	E-APP-LEFT	W-APP-LEFT
	PHASE 1		PHASE 2		PHASE 3		PHASE 4	
TIME	57.		33.		-0.		-0.	
V/GC	.52973		0.00000		0.00000		0.00000	
DELA	10.	22.	0.	0.	10.	22.	0.	0.
QUEUE	1.	4.	0.	0.	0.	0.	0.	0.
VOLUME	822.	1368.	0.	0.	0.	0.	0.	0.
CAPACITY	1550.	1549.	1.	1.	0.	0.	0.	0.
V/GCAP	.31812	.52973	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

INTERSECTION 11

	NORTH-APPR	SOUTH-APPR	EAST-APPR	WEST-APPR	N-APP-LEFT	S-APP-LEFT	E-APP-LEFT	W-APP-LEFT
	PHASE 1		PHASE 2		PHASE 3		PHASE 4	
TIME	57.		33.		-0.		-0.	
V/GC	.49723		0.00000		0.00000		0.00000	
DELA	9.	17.	0.	0.	9.	17.	0.	0.
QUEUE	0.	2.	0.	0.	0.	0.	0.	0.
VOLUME	832.	1492.	0.	0.	0.	0.	0.	0.
CAPACITY	1800.	1800.	1.	1.	0.	0.	0.	0.
V/GCAP	.27728	.49723	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

INTERSECTION 12

	NORTH-APPR	SOUTH-APPR	EAST-APPR	WEST-APPR	N-APP-LEFT	S-APP-LEFT	E-APP-LEFT	W-APP-LEFT
	PHASE 1		PHASE 2		PHASE 3		PHASE 4	
TIME	57.		33.		-0.		-0.	
V/GC	.55410		0.00000		0.00000		0.00000	
DELA	8.	26.	0.	0.	8.	26.	0.	0.
QUEUE	0.	6.	0.	0.	0.	0.	0.	0.
VOLUME	622.	1616.	0.	0.	0.	0.	0.	0.
CAPACITY	1751.	1750.	1.	1.	0.	0.	0.	0.
V/GCAP	.21318	.55410	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

INTERSECTION 13

	NORTH-APPR	SOUTH-APPR	EAST-APPR	WEST-APPR	N-APP-LEFT	S-APP-LEFT	E-APP-LEFT	W-APP-LEFT
	PHASE 1		PHASE 2		PHASE 3		PHASE 4	
TIME	57.		33.		-0.		-0.	
V/GC	.42617		0.00000		0.00000		0.00000	
DELA	9.	13.	0.	0.	9.	13.	0.	0.
QUEUE	0.	1.	0.	0.	0.	0.	0.	0.
VOLUME	1099.	1598.	0.	0.	0.	0.	0.	0.
CAPACITY	2250.	2250.	1.	1.	0.	0.	0.	0.
V/GCAP	.29305	.42617	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

INTERSECTION 14

	NORTH-APPR	SOUTH-APPR	EAST-APPR	WEST-APPR	N-APP-LEFT	S-APP-LEFT	E-APP-LEFT	W-APP-LEFT
	PHASE 1		PHASE 2		PHASE 3		PHASE 4	
TIME	57.		33.		-0.		-0.	
V/GC	.47951		0.00000		0.00000		0.00000	
DELA	7.	15.	0.	0.	7.	15.	0.	0.
QUEUE	0.	2.	0.	0.	0.	0.	0.	0.
VOLUME	544.	1798.	0.	0.	0.	0.	0.	0.
CAPACITY	2251.	2250.	1.	1.	0.	0.	0.	0.
V/GCAP	.14499	.47951	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

INTERSECTION 15

	PHASE 1		PHASE 2		PHASE 3		PHASE 4	
TIME	57.		33.		-0.		-0.	
V/GC	.55368		0.00000		0.00000		0.00000	
	NORTH-APPR	SOUTH-APPR	EAST-APPR	WEST-APPR	N-APP-LEFT	S-APP-LEFT	E-APP-LEFT	W-APP-LEFT
DELA	8.	23.	0.	0.	8.	23.	0.	0.
QUEUE	0.	6.	0.	0.	0.	0.	0.	0.
VOLUME	759.	2076.	0.	0.	0.	0.	0.	0.
CAPACITY	2250.	2250.	1.	1.	0.	0.	0.	0.
V/GCAP	.20242	.55368	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

INTERSECTION 16

	PHASE 1		PHASE 2		PHASE 3		PHASE 4	
TIME	57.		33.		-0.		-0.	
V/GC	.46740		.23774		0.00000		0.00000	
	NORTH-APPR	SOUTH-APPR	EAST-APPR	WEST-APPR	N-APP-LEFT	S-APP-LEFT	E-APP-LEFT	W-APP-LEFT
DELA	0.	14.	29.	0.	0.	14.	29.	0.
QUEUE	0.	2.	1.	0.	0.	0.	0.	0.
VOLUME	0.	1928.	656.	0.	0.	0.	0.	0.
CAPACITY	1.	2475.	920.	1.	0.	0.	0.	0.
V/GCAP	0.00000	.46740	.23774	0.00000	0.00000	0.00000	0.00000	0.00000

LINK	TRAVEL TIMES			LINK	TRAVEL TIMES			LINK	TRAVEL TIMES			LINK	TRAVEL TIMES			LINK	TRAVEL TIMES			LINK	TRAVEL TIMES		
1	113.	113.	113.	2	115.	115.	115.	3	35.	35.	35.	4	35.	35.	35.	5	82.	82.	82.	6	93.	93.	93.
7	136.	136.	136.	8	134.	134.	134.	9	97.	97.	97.	10	112.	112.	112.	11	35.	35.	35.	12	48.	48.	48.
13	21.	21.	21.	14	13.	13.	13.	15	46.	46.	46.	16	47.	47.	47.	17	65.	65.	65.	18	70.	70.	70.
19	36.	36.	36.	20	39.	39.	39.	21	18.	18.	18.	22	27.	27.	27.	23	118.	118.	118.	24	120.	120.	120.
25	17.	17.	17.	26	19.	19.	19.	27	30.	30.	30.	28	49.	49.	49.	29	110.	110.	110.	30	122.	122.	122.
31	32.	32.	32.	32	50.	50.	50.	33	141.	141.	141.	34	152.	152.	152.	35	125.	125.	125.	36	120.	120.	120.
37	29.	29.	29.	38	45.	45.	45.	39	26.	26.	26.	40	43.	43.	43.	41	83.	83.	83.	42	80.	80.	80.
43	133.	133.	133.	44	156.	156.	156.	45	109.	109.	109.	46	80.	80.	80.	47	42.	42.	42.	48	46.	46.	46.
49	106.	106.	106.	50	132.	132.	132.	51	63.	63.	63.	52	79.	79.	79.	53	40.	40.	40.	54	49.	49.	49.
55	22.	22.	22.	56	27.	27.	27.	57	68.	68.	68.	58	85.	85.	85.	59	32.	32.	32.	60	42.	42.	42.
61	48.	48.	48.	62	62.	62.	62.	63	23.	23.	23.	64	31.	31.	31.	65	54.	54.	54.	66	74.	74.	74.
67	31.	31.	31.	68	42.	42.	42.	69	70.	70.	70.	70	96.	96.	96.	71	67.	67.	67.	72	91.	91.	91.
73	21.	21.	21.	74	29.	29.	29.	75	166.	166.	166.	76	226.	226.	226.	77	58.	58.	58.	78	74.	74.	74.
79	55.	55.	55.	80	85.	85.	85.	81	60.	60.	60.	82	92.	92.	92.	83	58.	58.	58.	84	93.	93.	93.
85	42.	42.	42.	86	66.	66.	66.	87	78.	78.	78.	88	92.	92.	92.	89	92.	92.	92.	90	108.	108.	108.
91	41.	41.	41.	92	49.	49.	49.	93	62.	62.	62.	94	73.	73.	73.	95	30.	30.	30.	96	35.	35.	35.
97	89.	89.	89.	98	96.	96.	96.	99	132.	132.	132.	100	141.	141.	141.	101	61.	61.	61.	102	65.	65.	65.
103	81.	81.	81.	104	83.	83.	83.																

TOTAL TRAVEL TIME ON NETWORK 3215.(VEH-HRS)
TOTAL RUNNING TIME IN PARKING ZONES 0.(VEH-HRS)
TOTAL VEHICLE MILES TRAVELED ON NETWORK 116300.(VEH-MI)

TOTAL INTERSECTION DELAY ON NETWORK 95.(VEH-HRS)
TOTAL STOPS AT INTERSECTIONS 16396.(VEH)
TOTAL OF INTERSECTION AVERAGE QUEUE LENGTHS 1167.(FT)

SRI NETWORK MODEL
OF AUTOMOBILE EXHAUST EMISSIONS AND GASOLINE CONSUMPTION

1975 Tidewater Corridor Test on Corridor 2, Baseline
Hour = 8, Rate of Speed Changes = 5.00 Ft/Sec/Sec.
(CO2 Emissions at 1971 Levels)

TOTAL EXHAUST EMISSIONS (gm)

LINK NO.	HC	CO	CO2	NOX		
1	1266.	12904.	204627.	1759.	GALLONS GAS	26.6
2	1739.	17770.	279443.	2367.	GALLONS GAS	36.4
3	388.	3955.	62716.	539.	GALLONS GAS	8.2
4	533.	5446.	85646.	726.	GALLONS GAS	11.2
5	1205.	12311.	193825.	1646.	GALLONS GAS	25.2
6	1937.	20634.	269431.	2268.	GALLONS GAS	36.0
7	2192.	22971.	322143.	2742.	GALLONS GAS	42.6
8	3886.	40080.	610003.	4881.	GALLONS GAS	79.8
9	1355.	14184.	204621.	1489.	GALLONS GAS	27.0
10	3265.	35166.	427096.	3074.	GALLONS GAS	57.8
11	279.	3057.	34091.	303.	GALLONS GAS	4.7
12	910.	10354.	92630.	787.	GALLONS GAS	13.3
13	329.	3742.	33924.	300.	GALLONS GAS	4.8
14	345.	3534.	55288.	464.	GALLONS GAS	7.2
15	462.	4696.	75141.	656.	GALLONS GAS	9.8
16	1245.	12741.	199342.	1674.	GALLONS GAS	26.0
17	887.	8652.	159669.	1799.	GALLONS GAS	20.4
18	1867.	18409.	327807.	3454.	GALLONS GAS	42.1
19	487.	4756.	87778.	989.	GALLONS GAS	11.2
20	1026.	10120.	180211.	1899.	GALLONS GAS	23.1
21	251.	2447.	45161.	509.	GALLONS GAS	5.8
22	1315.	16779.	131412.	1284.	GALLONS GAS	19.3
23	1269.	13398.	166828.	1298.	GALLONS GAS	22.5
24	2306.	24302.	341572.	2370.	GALLONS GAS	45.2
25	157.	1645.	23738.	173.	GALLONS GAS	3.1
26	539.	5832.	58132.	490.	GALLONS GAS	8.1
27	618.	6675.	70863.	566.	GALLONS GAS	9.8
28	1577.	17969.	151189.	1097.	GALLONS GAS	21.9
29	1771.	19396.	222065.	1341.	GALLONS GAS	30.3
30	3537.	39123.	417640.	2386.	GALLONS GAS	57.7
31	612.	6809.	62893.	432.	GALLONS GAS	8.9
32	1740.	20295.	157191.	1011.	GALLONS GAS	23.2
33	1881.	19921.	262598.	1951.	GALLONS GAS	35.1
34	5095.	54609.	681383.	4804.	GALLONS GAS	91.8
35	2936.	31333.	398906.	2896.	GALLONS GAS	53.6
36	4244.	44868.	623124.	4230.	GALLONS GAS	82.5
37	643.	6750.	96056.	682.	GALLONS GAS	12.7
38	1940.	21651.	198185.	1484.	GALLONS GAS	28.2
39	373.	4086.	38796.	312.	GALLONS GAS	5.5
40	2161.	24942.	188523.	1395.	GALLONS GAS	28.0
41	1388.	14824.	183583.	1370.	GALLONS GAS	24.8
42	3450.	36608.	500998.	3310.	GALLONS GAS	66.5
43	1728.	18075.	261183.	1906.	GALLONS GAS	34.4
44	6233.	67145.	824837.	5702.	GALLONS GAS	111.3
45	1585.	17451.	186266.	1353.	GALLONS GAS	25.8
46	665.	6958.	100615.	735.	GALLONS GAS	13.3
47	250.	2543.	40911.	361.	GALLONS GAS	5.3
48	2322.	24022.	361515.	2836.	GALLONS GAS	47.4
49	670.	8445.	158423.	1844.	GALLONS GAS	20.2
50	7722.	77334.	1305616.	12515.	GALLONS GAS	168.6
51	520.	5046.	94669.	1102.	GALLONS GAS	12.1
52	4614.	46212.	780195.	7478.	GALLONS GAS	100.7
53	412.	4013.	74584.	852.	GALLONS GAS	9.5
54	1912.	19167.	322787.	3081.	GALLONS GAS	41.7
55	227.	2212.	41104.	470.	GALLONS GAS	5.2
56	1054.	10563.	177892.	1698.	GALLONS GAS	23.0
57	2346.	23061.	415355.	4470.	GALLONS GAS	53.2
58	6000.	61055.	974954.	8483.	GALLONS GAS	126.7
59	1409.	13930.	245930.	2552.	GALLONS GAS	31.6
60	3335.	34430.	521777.	4144.	GALLONS GAS	68.3
61	2075.	20509.	362074.	3757.	GALLONS GAS	46.5
62	4909.	50690.	768195.	6101.	GALLONS GAS	100.5
63	1121.	11126.	193810.	1963.	GALLONS GAS	24.9
64	2695.	28209.	406387.	2950.	GALLONS GAS	53.6
65	2631.	26107.	454757.	4606.	GALLONS GAS	58.5

TOTAL EXHAUST EMISSIONS (gm)

LINK NO.	HC	CO	CO2	NOX		
66	6323.	66189.	953548.	6921.	GALLONS GAS	125.7
67	1489.	14778.	257413.	2607.	GALLONS GAS	33.1
68	3579.	37466.	539752.	3916.	GALLONS GAS	71.1
69	3422.	33958.	591505.	5991.	GALLONS GAS	76.1
70	8224.	86093.	1240286.	9002.	GALLONS GAS	163.5
71	3233.	32083.	558852.	5660.	GALLONS GAS	71.9
72	7770.	81340.	1171818.	8505.	GALLONS GAS	154.4
73	1022.	10146.	176725.	1790.	GALLONS GAS	22.7
74	2457.	25722.	370562.	2690.	GALLONS GAS	48.8
75	7952.	78880.	1376376.	13984.	GALLONS GAS	177.0
76	19368.	202699.	2923228.	21257.	GALLONS GAS	385.2
77	2099.	20646.	370595.	3963.	GALLONS GAS	47.5
78	5510.	56392.	682503.	7414.	GALLONS GAS	115.0
79	1857.	18458.	319831.	3209.	GALLONS GAS	41.2
80	5382.	57732.	757663.	4623.	GALLONS GAS	101.2
81	2009.	19966.	345950.	3471.	GALLONS GAS	44.5
82	5822.	62446.	819538.	5000.	GALLONS GAS	109.5
83	1913.	18999.	330371.	3336.	GALLONS GAS	42.5
84	5571.	64355.	828919.	4876.	GALLONS GAS	111.0
85	1371.	13612.	236689.	2390.	GALLONS GAS	30.5
86	4278.	46106.	593864.	3493.	GALLONS GAS	79.6
87	2162.	21343.	378566.	3961.	GALLONS GAS	48.6
88	4173.	42291.	665095.	6111.	GALLONS GAS	88.9
89	2544.	25111.	445401.	4660.	GALLONS GAS	57.2
90	4910.	49758.	806047.	7190.	GALLONS GAS	104.6
91	980.	9642.	173300.	1856.	GALLONS GAS	22.2
92	2083.	21000.	346325.	3187.	GALLONS GAS	44.8
93	1464.	14400.	258837.	2775.	GALLONS GAS	33.2
94	3111.	31365.	517263.	4760.	GALLONS GAS	67.0
95	709.	6973.	125338.	1344.	GALLONS GAS	16.1
96	1506.	15188.	250476.	2305.	GALLONS GAS	32.4
97	1741.	17059.	310203.	3396.	GALLONS GAS	39.7
98	3074.	30487.	532149.	5410.	GALLONS GAS	68.4
99	1543.	15036.	278711.	3167.	GALLONS GAS	35.6
100	3226.	31706.	571348.	6154.	GALLONS GAS	73.2
101	710.	6915.	128178.	1457.	GALLONS GAS	16.4
102	1484.	14581.	262760.	2830.	GALLONS GAS	33.7
103	670.	6520.	121673.	1401.	GALLONS GAS	15.5
104	1245.	12162.	223802.	2508.	GALLONS GAS	28.6

Appendix D

TECHNICAL RATIONALE FOR METHODOLOGICAL PROCEDURES

Appendix D

TECHNICAL RATIONALE FOR METHODOLOGICAL PROCEDURES

The purpose of this appendix is to elaborate to some extent the technical assumptions underlying five basic components of the assessment methodology developed in the report:

- Link and intersection capacity estimation
- Intersection delay and queuing estimation
- Pollutant emissions
- Fuel consumption
- Local estimates of air quality.

Capacity Considerations

The capacity of a road link is the number of vehicles able to traverse the link under specified physical and operational conditions. The Highway Capacity Manual (Ref. 12) and the Capacity Analysis Techniques (Reference 13) provide the basis for the methods used in our assessment procedure.

Free flow capacity is computed on the basis of the relationship

$$C = 2000\ LWT \tag{D-1}$$

where C is the maximum number of vehicles able to traverse the link in the course of an hour, L is the number of lanes, W is an adjustment for lane width and lateral clearance, and T is a truck factor to account for reduced capacity when heavy-duty vehicles are in the stream. Factors W and T are provided in Tables A-1 and A-2 of Appendix A.

Capacity of signed and signalized intersections is calculated in our methodology on the basis of graphical techniques given in Reference 11 for signalized intersections. Reference 11 provides separate techniques for a variety of intersection characteristics. We have based our estimates on the technique for average conditions consisting of 10% left and right turners, 5% heavy-duty vehicles in the stream, and no local bus stops. Figure A-3 (Appendix A) is appropriate for typical intersections of two-way roads under the average conditions specified. When conditions differ substantially from those assumed here, the analyst should consult the references for guidance. Although Figure A-3 is intended primarily for signalized intersections, signed intersections and

toll booths can be treated as though they were signalized intersections if a pseudo-value of green/cycle ratio is chosen to properly represent the degree of interruption. In the case of stop and yield signs, we have assumed that intersection capacity is about 75% of saturation flow if free passage through any cross stream of traffic is allowed (Ref. 12). This assumption permits treatment of signed intersections with full cross-stream tolerance as signalized intersections with a green/cycle ratio of 0.75 for the purpose of capacity determination. When less than full cross-stream tolerance prevails, we provide for a correction based on the ratio of excess capacity in the cross stream to the full tolerance capacity of the signed intersection. In the case of tool booths, the capacity of each gate is directly related to gate headway, that is, the average time interval between vehicles exiting the gate. Gate capacity (Cg) may be calculated as

$$Cg = \frac{3600}{H} \text{ (veh/gate/hr)} \quad , \qquad \text{(D-2)}$$

where H is gate headway in seconds. In subsequent calculations of delay and queuing, individual gate capacity rather than full approach capacity and lane volume rather than link volume must be used to properly model the toll booth situation.

<u>Delay Considerations</u>

Delay at signalized intersections is typically computed using models formulated by Webster (Ref. 14) in which delay (D) is given by

$$D = \frac{CyS(1 - G/Cy)^2}{2(S - V)} + \frac{1800\ VCy^2}{SG(SG - VCy)} + B_1 \qquad \text{(D-3)}$$

or by Newell (Ref. 15), in which

$$D = \frac{CyS(1 - G/Cy)^2}{2(S - V)} + \frac{1800\ CyIH(\mu)}{SG - VCy} + B_2 \qquad \text{(D-4)}$$

where S = saturation flow (veh/hr)

G = green time (sec)

Cy = cycle length (sec)

and V = demand volume (veh/hr)

Quantities B_1 and B_2 are relatively small empirical correction factors and $IH(\mu)$ is a function measuring the variation in vehicle arrivals and departures.

In the manual technique (Figure A-5a, Appendix A), the Webster model is used for undercapacity intersections, whereas the Newell model is

employed in the automated (computer) method. In practice, there is little difference in the delay estimates produced by the two methods. In the case of overcapacity intersections, little guidance is available for estimating delay. We have made the simple assumption that in such situations, delays up to one cycle length can be treated with the under-capacity model. Excess delay (D+) is then estimated as the average time required for a vehicle to traverse the queue remaining at the end of any given signal cycle. If the average length of such remaining queues is assumed equal to one-half the hourly excess of approach volume over approach capacity, excess delay in seconds may be estimated as

$$D+ = \frac{3600}{C}\left(\frac{V-C}{2}\right) \quad . \qquad \text{(D-5)}$$

Excess delay is then added to cycle length as an estimate of total delay for an overcapacity signalized intersection. The same basic approach is used in both the manual and computerized methods.

Stopping rate and queue length are also important quantities associated with intersection delay. The proportion of vehicles (P) that stop for a signal is given by Webster (Ref. 14) as

$$P = \frac{1 - G/Cy}{1 - V/S} \quad , \qquad \text{(D-6)}$$

so that the stopping rate or the number of vehicles (N) that stop at the intersection in the course of an hour is given by

$$N = PV \quad . \qquad \text{(D-7)}$$

Equations (D-6) and (D-7) are the basis for Figure A-4 (Appendix A).

Queue length at signalized intersections can be computed on the basis of the delay models in terms of the arrival rate of vehicles and the headway or service rate of the intersection. In the automated method, queuing is determined by applying a Poisson distribution to the arrival rate of vehicles and applying the Newell queuing model. In the manual method, since queue length is used primarily to define a length of intersection approach over which excess emissions apply, we have used a simplified approach. A minimum length of 40 meters is defined to encompass excess emissions due to idling (stopped) vehicles and excess emissions due to vehicles accelerating or decelerating at the intersection (Ref. 7). For queues in excess of 40 meters we have defined queue length (X_q), in meters, as

$$X_q = 8\left(\frac{DC}{3600}\right)\frac{1}{L} = \frac{DC}{450\ L} \quad , \qquad \text{(D-8)}$$

where the quantity in parentheses is the number of vehicles in the queue, the quantity 8 represents an average distance of 8 meters between tail pipes, and L is the number of lanes available to accommodate the queue. Equation (D-8), which is the basis for Figure A-7 (Appendix A), assumes

that D, the average delay per vehicle, can be taken to represent the average time required for a vehicle to make its way through the length of the average queue.

For nonsignalized intersections, in both the manual and automated methods, delay (in seconds) is computed on the basis of classical queuing theory as

$$D = \frac{3600}{C}\left(\frac{V}{C-V}\right) \quad . \tag{D-9}$$

Equation (D-9) is the basis for Figure A-6. Queue length is obtained in the same manner for nonsignalized as for signalized intersections as

$$X_q = \frac{8N_q}{L} \tag{D-10}$$

where N_q is the number of vehicles in the queue.

Pollutant Emissions

The emissions submodel of NAFCOM is based on a method of calculating the amount of carbon monoxide (CO) produced by specified distributions of light-duty vehicles under four operating conditions: combinations of constant speed, acceleration, deceleration, and idling (Ref. 3). The formulation centers around an instantaneous emission rate $\dot{e}(t)$ that is a function of vehicle speed (v) and acceleration (a). Since speed and acceleration are functions of time, the emission rate function can be expressed as

$$\dot{e}(t) = e\left[v(t), a(t)\right] \tag{D-11}$$

By assuming that speed is perturbation to the steady-state emission rate, two equations describe the emission rate:

$$\begin{aligned}\dot{e}(v,a) = {} & b_1 + b_2 v + b_3 a + b_4 av + b_5 v^2 \\ & + b_6 a^2 + b_7 v^2 a + b_8 a^2 v + b_9 a^2 v^2 \quad ,\end{aligned} \tag{D-12}$$

$$\dot{e}(v,0) = b_{10} + b_{11} v + b_{12} v^2 \tag{D-13}$$

where Eq. (D-12) describes the nonzero-acceleration emission rate, and Eq. (D-13) determines the steady-state emission rate. In the original formulation, the coefficients (b_1 to b_{12}) were then determined for 11 different vehicle-model groups.

Instead of using the 11 equations with 12 coefficients each to describe the emissions for a variable vehicle mix, NAFCOM assumes a

constant mix (Table D-1) and therefore requires only two sets of coefficients (one for high-altitude sites and one for low-altitude sites) to calculate the emission rate. Table D-2 shows the two sets of b_i values.

Table D-1

CONSTANT VEHICLE MODEL MIX ASSUMED IN NAFCOM FOR BOTH HIGH- AND LOW-ALTITUDE SITES

Model Year	Mix (percent of total vehicles)
1957-1967	57 %
1968	10.2
1969	10.6
1970	10.4
1971	11.8

Table D-2

COEFFICIENTS OF EMISSION RATE EQUATIONS

	High Altitude	Low Altitude
b_1	1.019	0.551
b_2	-0.056	-0.02
b_3	0.040	0.052
b_4	0.015	1.93×10^{-3}
b_5	0.015	3.41×10^{-4}
b_6	-0.156	-0.03
b_7	3.52×10^{-5}	4.99×10^{-5}
b_8	0.020	3.75×10^{-3}
b_9	-2.67×10^{-4}	-2.26×10^{-5}
b_{10}	0.310	0.284
b_{11}	-4.68×10^{-3}	-3.75×10^{-3}
b_{12}	3.15×10^{-4}	1.16×10^{-4}

The appropriate coefficients, speed, and acceleration rates are then applied to Eqs. (D-12) or (D-13) to determine the emission rate. Since some of the coefficients are negative, it is possible for some of the emission rates to be negative. To prevent this, NAFCOM compares the computed emission rate with a predetermined minimum value and chooses the larger of the two for the emission rate calculations.

Emissions are updated from base year 1971 to future years on the assumption of replacement of older by newer model years in the mix at a fixed rate and assuming that prescribed emission standards are met for the newer models.

In the manual method, updated modal emission rates based on the Kunzelman model (Ref. 3) are portrayed as an average over the assumed mix for base year 1975 in Figures 6 and 7 (pp. 31 and 32) with updating to future years in terms of factors in Table 3 (p. 18).

Local Estimates of Air Quality

The estimation of air quality at a given site involves the separate estimation of two components: the air quality background due to pollutant emissions over the entire community within which the site is located and the contribution from sources in the immediate vicinity of the site. The two components are computed separately and added to obtain total air quality. Figure D-1 (based on Ref. 16) provides a graphical method for estimating air quality background on an annual average basis of communitywide emission density and annual average wind speed are known. Figure D-2 (based on Ref. 17) provides a graphical conversion of the annual average background value obtained from Figure D-1 to an estimate of the highest value expected in the course of a year (worst case) for different averaging times. Finally, Figure D-3 (based on Ref. 6) provides a method of estimating the contribution from nearby roads if the angle between the road and the wind direction is known, along with the roadway emission density and the normal distance between road centerline and the site in question. Figure D-3 assumes a low wind speed (2 meters per second) to simulate a worst-case situation. Figures D-1 through D-3 can be used to obtain a first approximation of worst-case carbon monoxide levels at sites in the immediate vicinity of roadways.

In the manual method, air quality is calculated assuming a wind angle of 30 degrees with the road as a worst case, yielding a concentration/emission ratio of approximately 145 from Figure D-3. In our methodology demonstration, we estimated background using Figures D-2 and D-2 with emission density data contained in Reference 18.

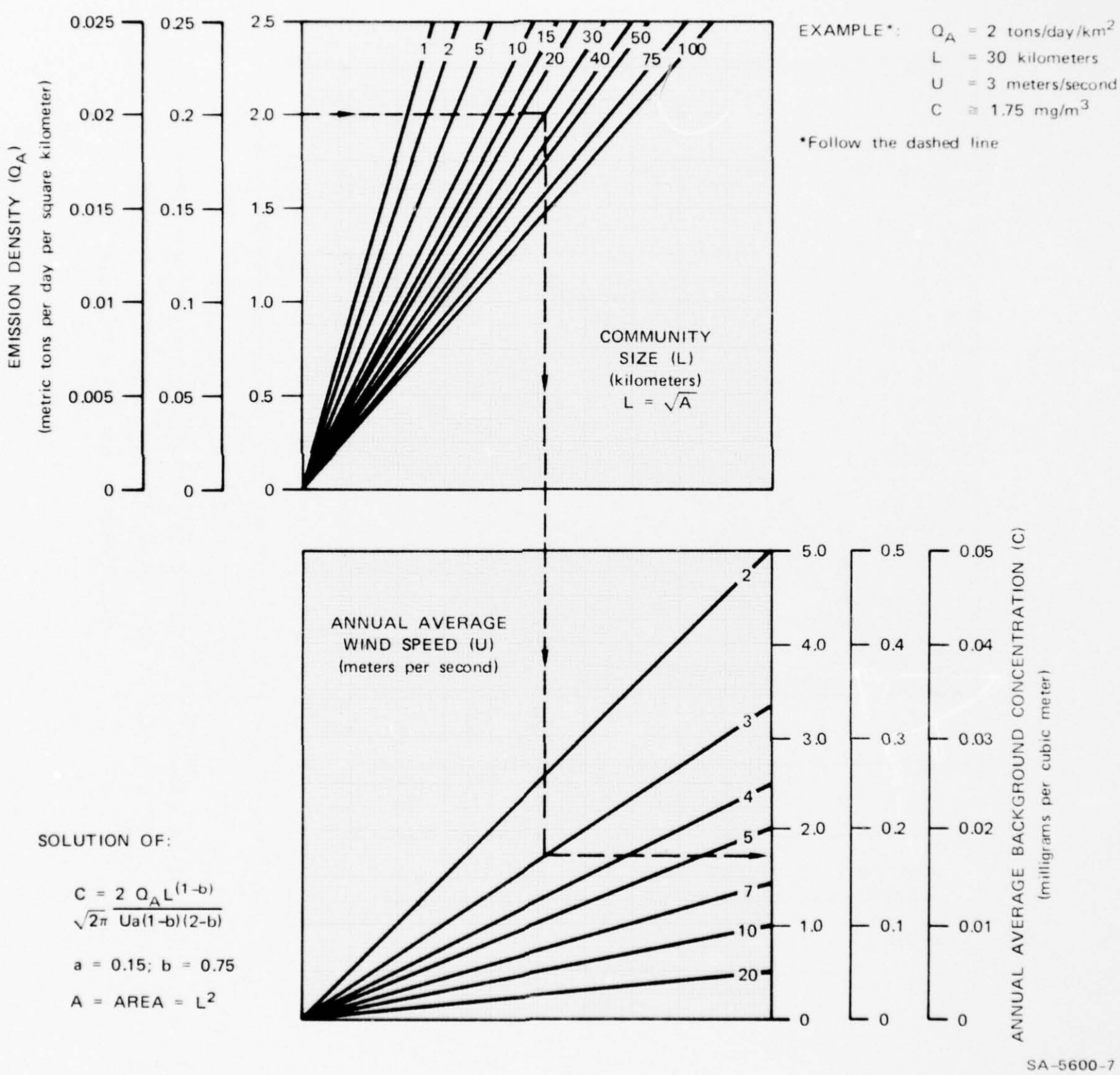
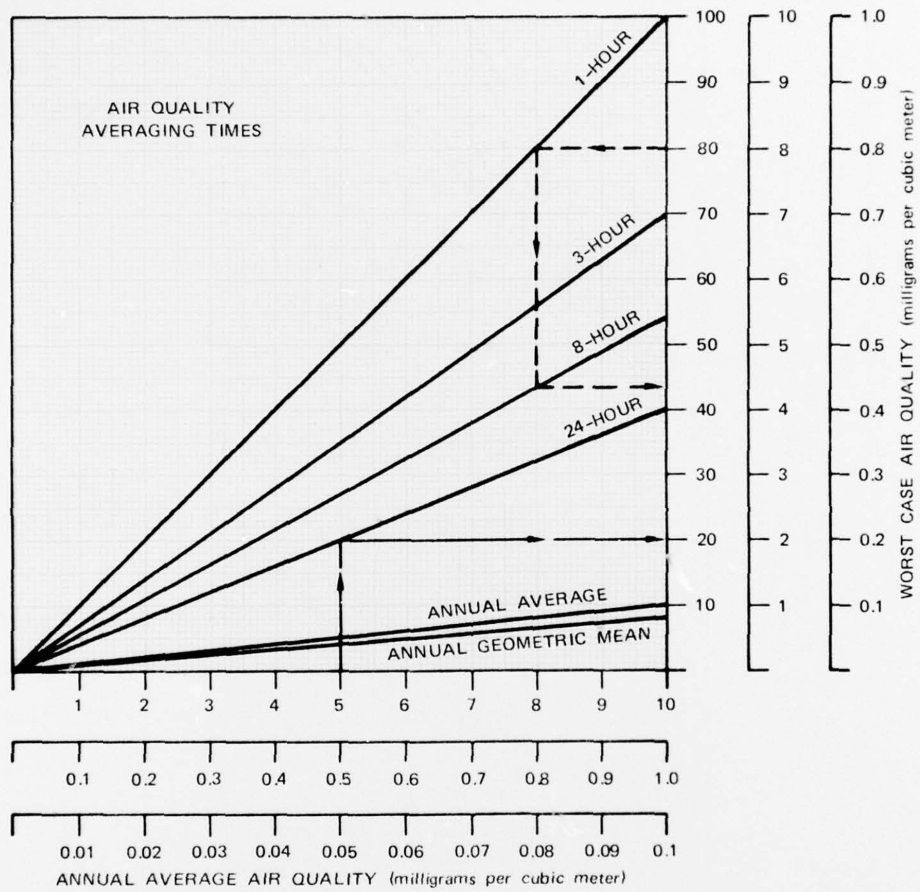


FIGURE D-1 GRAPHICAL CALCULATION OF AIR QUALITY BACKGROUND CONCENTRATION



EXAMPLES:

Conversion of annual average to worst case 24-hour average

Conversion of worst case 1-hour average to worst case 8-hour average

SA-5600-4

FIGURE D-2 GRAPHICAL CONVERSION OF AVERAGING TIME

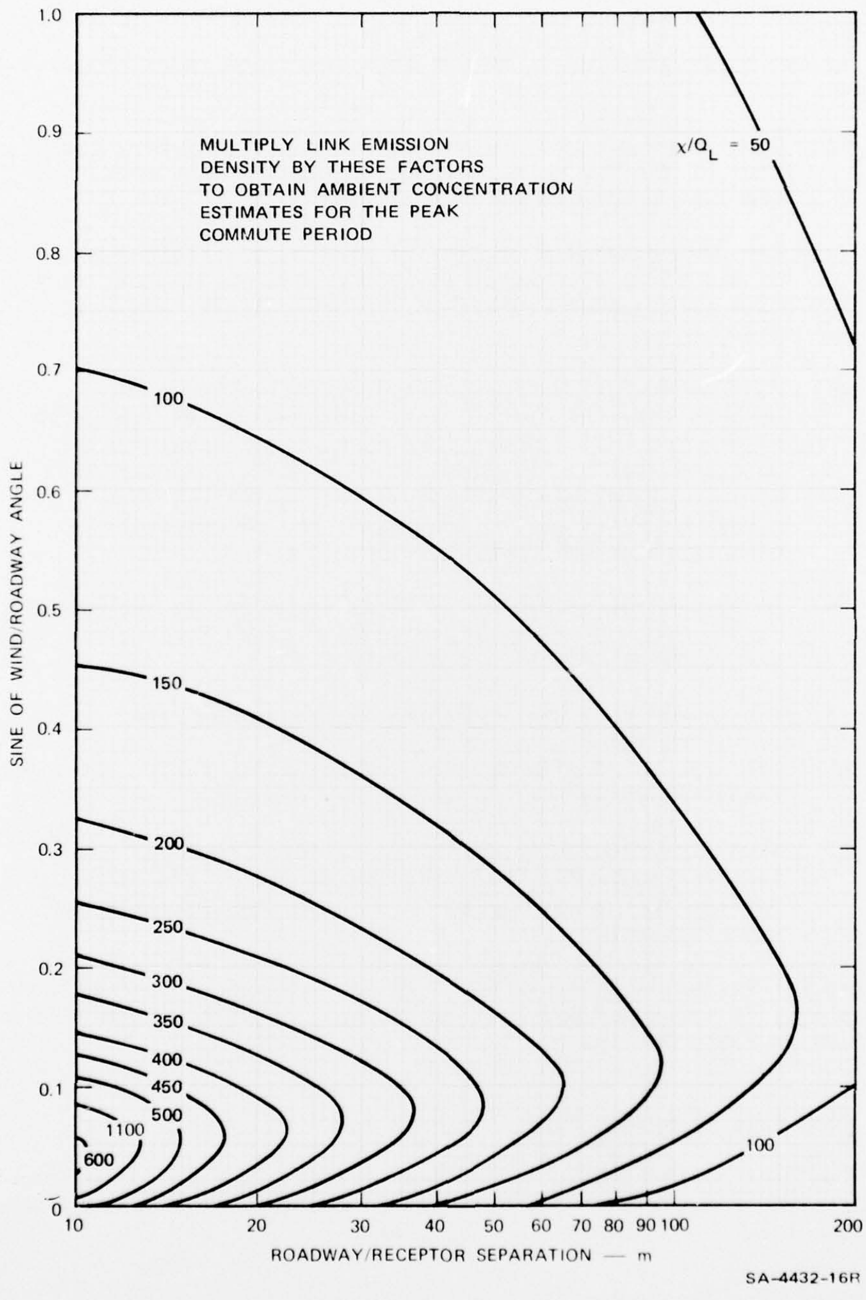


FIGURE D-3 GRAPHICAL CONVERSION OF LINK EMISSION DENSITY, E (g/m-sec) TO AMBIENT CONCENTRATION χ (mg/m^3) AS A FUNCTION OF WIND ANGLE AND NORMAL DISTANCE FROM THE LINK CENTERLINE

Input Characteristics

As currently structured, NAFCOM requires seven types of input information:

(1) The number of cards to be read into the computer, the hour of the day to be modeled, the day of the week, and the time period to be modeled.

(2) For each direction of traffic flow on a street segment (i.e., link) the number of lanes; x,y coordinates; link capacity; speed; connections to other links; and emission height.

(3) Each intersection is specified by the entering link numbers from the north, east, south, and west, the type of control (i.e., none, stop sign, fixed time signal, actuated signal), maximum cycle length if signalized, minimum signal phase lengths if signalized, yellow clearance interval if signalized, and the capacity of each approach per hour of green.

(4) Local area description, including vehicle mix, background carbon monoxide levels, altitude of site, latitude of site, and vertical diffusion constant.

(5) The number of venicles currently using each link.

(6) The x,y coordinates of receptor locations for which carbon monoxide concentrations are to be computed.

(7) Wind direction and speed. If stability is to be calculated by the model, the fraction of opaque clouds covering the sky is also input; otherwise stability class is input directly.

The input information is provided in the form of eight punched card types. The card types are described as follows, with details of the card images provided in Table D-3 (page).

Card Type 0--Header Card

The first data card for each time period is a header card containing the date and a descriptor that identifies the run. The descriptor may consist of any 70 alphanumeric characters.

Card Type 1--Run Description

For each time period the header card is followed by card type 1. This card denotes how many of each of the other card types should be

read for that time period. If the data on a card type do not change from one time period to the next, the card type 1 for the second time period should have a zero or spaces in the proper columns to indicate that the data have not changed and no new cards of a particular type should be read.

Card type 1 also contains the time of day (TOD) and the day of week (DOW). The input value for time of day should be the beginning of the period being simulated; e.g., when computing hourly concentrations, TOD is 8 for the period 0800-0900 LST. For day of week, 1 is Sunday, 2 is Monday, and so forth. The length of time being simulated with each iteration of NAFCOM is specified as TP. This value can be meaningfully varied from 900 seconds (15 minutes) to 7200 seconds (2 hours). In general, traffic demands and meteorological data are available as 1-hour summaries; for this reason the usual vlue for TP is 3600.

Card Type 2--Link Description

Each direction of flow on a street within the network is assigned a link number. A card type 2 is read for each link and includes the link number. The average number of lanes of traffic that make up the link is specified, and link capacity is determined when such capacity is not input (at 1200 veh/lane for speeds less than 70 ft/sec and 1800 veh/lane for speeds greater than 70 ft/sec).

Coordinates must be read that specify each link's end points in the horizontal plane. While it would be possible to use different end points for the two links that define the two directions of flow on a typical street, we feel such definition would be superfluous and that identical end points should be specified. Coordinates are input either in feet or in grid units from some arbitrary origin and must be positive. If grid units are used, a scale factor must be specified for conversion to feet.

Link capacity may be input or left to be computed by NAFCOM. Usually a network is very insensitive to link capacity, intersection capacity being the controlling variable. The exception is a freeway or other limited-access road that might be included in the simulated network.

Speed, in ft/sec, on a link indicates the average speed that vehicles travel during low-use periods. This can usually be estimated as the speed limit on the link.

Link-to-link connections are specified for each link going straight, right, and left. When a link does not lead to another link, the connection should be input as zero or spaces.

An emission height must be input for elevated links. When modeling a facility located on relatively flat terrain, an emission height of zero is normally input for all traffic links. At present, depressed roadways are treated as surface emission sources, while roadways upwind of aerodynamic barriers may be assigned effective emission heights, as necessary.

Card Type 3--Intersection Description

An intersection description is required for each intersection in the network. An intersection can be defined as each connection between two or more links. The link numbers of streets entering the intersection from the north, east, south, and west are input parameters. If there is no link approaching from some cardinal direction, spaces or zeros should be entered.

A type of control for each intersection (I) must be specified as follows:

ITYPC(I) = -2 indicates a 4-way arterial stop.

ITYPC(I) = -1 indicates a 2-way arterial stop. The approach with the largest volume is considered to be uncontrolled, while the cross-traffic links are assumed to have stop signs.

ITYPC(I) = 0 indicates no control on any approach.

ITYPC(I) = 1 indicates a fixed time signal controller.

ITYPC(I) = 2 indicates a vehicle-actuated (VA) controller with possible separate left-turn phases for north-south and east-west traffic.

ITYPC(I) = 3 indicates a vehicle-actuated controller with each intersection approach controlled by a separate signal phasel During a green phase, left-turning vehicles do not have to cross an opposing traffic flow since the opposing traffic experiences a red signal.

ITYPC(I) = 4 indicates type 2 control on the north-south approaches and type 3 control on the east-west approaches. The north-south approaches are controlled by a vehicle-actuated controller during phase 1 of the signal cycle. If phase 3 is specified as having other than zero phase length, left turns from the north-south directions are made during phase 3. If phase 3 is specified as having a zero phase length, then left-turning vehicles are assumed to move during phase 1 and experience opposing vehicular flow. Phases 2 and 4 are exclusive green phases for the east and west approaches, respectively.

ITYPC(I) = 5 indicates type 3 control on the north-south approaches and type 2 control of the east-west approaches. Phases 1 and 3 are exclusive green

phases controlling the north and south approaches, respectively. The east-west approaches are controlled by a vehicle-actuated controller during phase 2 of the signal cycle. If phase 4 is specified as having other than zero phase length, left turns from the east-west directions are made during this phase. If phase 4 is specified as having a zero phase length, left-turning vehicles are assumed to move during phase 2 and to experience opposing vehicular flow.

The five controller types are intended to allow any fixed-time or vehicle-actated control to be simulated. The controllers are simplified, however, and cannot be used to exactly replicate leading or lagging left-turn phases, or 8-phase-full-quad-left signal controllers. It is often possible to adjust the capacity of an intersection to compensate for the lack of a more sophisticated simulated signal controller, and produce meaningful results. An 8-phase-quad-left control is best simulated by a type 2 controller.

Each signal controller must have a maximum cycle length specified, as well as nonzero phase times for each operating signal phase. For example, a simple fixed-time signal might have a 60-second cycle time and a 30-second north-south and 30-second east-west phase lengths. If phase 3 or phase 4 times are set to zero, the NAFCOM simulation assumes left turns are made through opposing traffic during phases 1 and 2. When specifying VA control, each phase time represents a minimum phase length. Green time is apportioned among the phases in proportion to the largest demand/capacity ratio on the controlled approaches. For example, a type 2 controlled intersection might have a maximum cycle length of 240 seconds, minimum north-south phase 1 and east-west phase 2 green times of 30 seconds, and minimum north-south left-turn phase 3 and east-west left-turn phase 4 green times of 10 seconds. This signal could operate at an 80-second cycle time under low demand conditions (30 + 30 + 10 + 10) and at a 240-second cycle time under high demand conditions. (Actually, if there is no demand for the east-west left-turn phase 4, phase skippability will be assumed and a 70-second minimum cycle time would be possible.)

A yellow clearance interval, CI(I), is specified for each controller. This interval is applied to each phase of each controller and decreases the effective green time of each signal phase by CI(I)/2.

Four approach capacities may be specified, one for each approach (or phase if the intersection is signalized). If an input capacity parameter is left blank, NAFCOM will determine a capacity based on the number of lanes on the approach link and the type of intersection control. Capacity of a signalized intersection approach can be determined by selecting the capacity per hour of green based on the road width from Figures 6.6 through 6.13 in the Highway Capacity Manual. The capacity so selected assumes 10% left-turning and 10% right-turning vehicles. NAFCOM adjusts the input capacity based on the percentage of vehicles actually routed

left and right in the modeled network. When a 3- or 4-phase and type 1 or 2 signal is specified, and third phase is assumed to be the north-south left-turn phase and the fourth phase is assumed to be the east-west left-turn phase. The capacities input should be the maximum of the left-turning approaches during the third or fourth phase. A type 3 intersection assumes the third and fourth phases control the south and east approaches and the third and fourth capacities are the capacities of these approaches.

Besides an adjustment for number of turning vehicles, NAFCOM assumes there is a left-turn lane where left-turn phases are specified. This has the effect of increasing capacity to the through vehicles, as well as to the left-turning vehicles.

Card Type 5--Local Area Description

Local area descriptors appear on card type 5. The user must input the percentage of heavy-duty vehicles in the total traffic, the altitude and latitude of the site, and the background CO concentrations at the site. A turning factor is input on this card, which can be used to adjust modeled emissions, based on measured emissions, or to adjust emissions based on different vehicle mixes and emission factors found in different parts of the United States or other countries.

Card type 5 also requires specification of a distance representing initial vertical diffusion. Suggested values for this parameter are in the range of 3-10 m. If a value less than 3 m is input, NAFCOM will set the constant equal to 3 m.

Card Type 8--Vehicle Counts

The purpose of this card is to specify the number of vehicles that currently use the network. The counts for as many as four links can be included on each card. The count on a link is broken down into vehicles traveling straight, turning right, or turning left at the downstream intersection of the link with other links. It is convenient to include the counts of four approaches to an intersection on a card. The input parameters are:

- North approach link number (L) followed by the counts on this approach traveling straight, right, and left.
- East approach link number (L2) followed by the counts on this approach traveling straight, right, and left.
- South approach link number (L3) followed by the counts on this approach traveling straight, right, and left.
- West approach link number (L4) followed by the counts on this approach traveling straight, right, and left.

Card Type 9--Receptor Description

The x- and y-coordinates of each receptor location are input on card type 9. The values for these coordinates are in feet and must be positive and based on the same origin used for link coordinates. The user may specify up to 200 receptor locations, but a receptor cannot be located on or within 10 m of a traffic link. There will be as many type 9 cards as there are receptors.

Card Type 10--Site Meteorology Description

Card type 10 contains the meteorological information necessary for dispersion calculations. The user has the option of specifying the stability class as input or allowing NAFCOM to calculate stability class from cloud cover and wind speed data. However, the stability determination capacity of NAFCOM can be used only when the time period being simulated is one hour. If stability is to be input, one card type 10, with values for wind direction, wind speed, and stability class, is input with traffic and site descriptors for each time period (durations of from 900 to 7200 seconds are possible). If NAFCOM is to calculate stability class, 24 type 10 cards containing observations of wind direction, wind speed, and cloud cover for 24 hours of the day are input with the traffic and site data for the first hour for which CO concentrations are to be computed. If stability is to be found by NAFCOM, the meteorological data for all 24 hours of a day are input together, even if CO computations are to be made for only a few hours of the day.

Other Card Types

Three additional card types (4, 6, and 7) not included here are required to invoke the potential of the program for zonal trip attraction/generation; routing of traffic through the network on a least-time basis, and treatment of pollutants emitted from vehicles operating in parking zones. Since exercise of these modeling options was beyond the scope of this particular project, we chose not to articulate these features in the interest of avoiding confusion. The reader is referred to Ref. 5 for a detailed treatment of these additional features of the model. Extension of the current methodology to include the exercise of such features will require additional research, especially with respect to the extension of the fuel consumption approach.

Output Characteristics

As currently structured, the following types of output information are available from NAFCOM:

- Delay time per vehicle, queue length, traffic volume, and capacity for each intersection approach.

- Travel time (seconds per vehicle) on each link for through, right-turning, and left-turning vehicles.
- Total travel time, intersection delay, and number of vehicles stopped on the network.
- Total pollutant emissions and gas consumption by network link.

An example of program output is provided in Appendix C in the form of an actual output from a run using the Tidewater demonstration data.

Table D-3

NAFCOM BASIC INPUT INFORMATION CARDS 0 THROUGH 10
(Data Read in by Subroutine INPT)

Card	Column	Format	Symbol	Units	Value Limits	Typical Value (default value in parentheses)	Description
0 Header	1-6	I6	NYEAR	--	710101 to 851231	741004	Date in year, month, day sequence
	7-76	7A10	LHEAD	--	--	EXAMPLE CENTER	Heading to precede output summary
1	1-2	I2	IC	--	--	--	Card type number
	3-5	I3	NLINK	--	0* to 200	154 (previously stored value)	Number of cards of type 2
	6-10	I5	NINS	--	0* to 70	48 (previously stored value)	Number of cards of type 3
	11-15	I5	NZONES	--	0* to 50	23 (previously stored value)	Number of cards of type 4
	16-20	I5	ICN	--	0 or 1	1 (previously stored value)	Number of cards of type 5
	21-25	I5	NGATE	--	0* to 10	7 (previously stored value)	Number of cards of type 6
	26-30	I5	NVETP	--	0* to 3	3 (previously stored value)	Number of cards of type 7
	31-35	I5	NCOUNT	--	0 to 200	15 (previously stored value)	Number of cards of type 8
	36-40	I5	NUMRECP	--	0* to 200	26 (previously stored value)	Number of cards of type 9
	41-45	I5	IMET	--	0* to 24	1 (previously stored value)	Number of cards of type 10
	46-50	F5.0	TOD	*Hours*	*0 to 23*	8	*Hour of day*
	51-55	F5.0	DOW	--	1 to 7	3	Day of week (Sun = 1, Mon = 2, ... Sat = 7)
	56-60	F5.0	TP	Sec	900 to 7200	3600	Time period duration

Table D-3 (Continued)

Card	Column	Format	Symbol	Units	Value Limits	Typical Value (default value in parentheses)	Description
1	61-65	F5.0	TOTATT	Vehicles	≥0	124	Total trips attracted to and generated by the indirect sources during time period specified
	66-70	F5.0	TOTGEN	Vehicles	≥0	74	
	71-75	F5.0	PD	ft^2/veh	≥1	360	Parking density constant (number of ft^2 required to park each vehicle)
	76-80	I5	ITM	--	1 to 10	1 (1)	Number of iterations of the route selection process
2	1-2	I2	IC	--	2	2	Card type number
	3-5	I3	L	--	0 to 200	1	Link number
	6-10	I5	NLAN	--	≥1	2	Number of lanes
	11-15	F5.0	X1(L)	ft	>0	3751	x-coordinate of northernmost end point (easternmost if link runs E-W)
	16-20	F5.0	Y1(L)	ft	>0	2363	y-coordinate of northernmost end point
	21-25	F5.0	X2(L)	ft	>0	2247	x-coordinate of southernmost end point
	26-30	F5.0	Y2(L)	ft	>0	2673	y-coordinate of southernmost end point
	31-35	I5	LCAP(L)	veh/hr	≥1	-0 (1800)	Capacity of link, veh/hr
	36-40	F5.0	VEL(L)	ft/sec	1 to 147	58	Speed, ft/sec
	41-45	I5	LCON(L,1)	--	0 to 200	3	Link-to-link connections. The link that L connects to, going straight
	46-50	I5	LCON(L,2)	--	0 to 200	144	The link that L connects to, going right
	51-55	I5	LCON(L,3)	--	0 to 200	141	The link that L connects to, going left
	56-60	F5.0	HEIGHT(L)	m	≥0	0	Emission height

Table D-3 (Continued)

Card	Column	Format	Symbol	Units	Value Limits	Typical Value (default value in parentheses)	Description
3	1-2	I2	IC	--	3	3	Card type number
	2-5	I3	I	--	0 to 70	1	Intersection number
	6-10	I5	LIN(I,J)	--	0 to 200	142	North link number
	11-15	I5	LIN(I,J)	--	0 to 200	4	East link number
	16-20	I5	LIN(I,J)	--	0 to 200	143	South link number
	21-25	I5	LIN(I,J)	--	0 to 200	1	West link number
	26-30	I5	ITYPC(I)	--	-2 to 5	2	Type control; -1 = 2-way stop; -2 = 4-way stop; 0 = no control; 2,3 = V/A control; 1 = fixed time control; 4 = type 2 N-S, type 3 E-W; 5 = type 3 N-S, type 2 E-W
							Type 1 Fixed Time Phases / Type 2 Actuated Phases / Type 3 Actuated Phases
	31-35	I5	CYCL(I)	sec	$\geq\Sigma$ PH(I,J)	200	Cycle / Max cycle / Max cycle
	36-39	F4.0	PH(I,J)	sec	≥ 0	10	N-S / Min N-S / Min N
	40-43	F4.0	PH(I,J)	sec	≥ 0	10	E-W / Min E-W / Min E
	44-47	F4.0	PH(I,J)	sec	≥ 0	0	N-S LT / Min N-S LT / Min S
	48-51	F4.0	PH(I,J)	sec	≥ 0	0	E-W LT / Min E-W LT / Min W
	52-55	F4.0	CI(I)	sec	≥ 0	3	Yellow time interval
	56-59	F4.0	GCAP(I,1)	veh/hr	≥ 0	3600 (1200 veh/hr/lane)	Capacity of one approach N (os S) for phase 1 per hr green
	60-63	F4.0	GCAP(I,2)	veh/hr	≥ 0	4000 (1200 veh/hr/lane)	Capacity of E (or W) phase 2 per hr green
	64-67	F4.0	GCAP(I,3)	veh/hr	≥ 0	0 (1200 veh/hr/lane)	Capacity of S or S-N phase 3 per hr green
	68-71	F4.0	GCAP(I,4)	veh/hr	≥ 0	0 (1200 veh/hr/lane)	Capacity of W or W-E phase 4 per hr green

Table D-3 (Continued)

Card	Column	Format	Sybmol	Units	Value Limits	Typical Value (default value in parentheses)	Description
5	1-2	I2	IC	--	5	5	Card type number
	3-5	I3	MIX	--	1, 2, or 3	2	Heavy-duty vehicle mix: 1 = 0%, 2 = 5%, 3 = 10%
	11-15	F5.0	BACKGRD	ppm	≥0	0	Background concentration at site
	16-20	F5.0	ALT	ft	≥0	0	Altitude of site
	21-25	F5.0	SLAT	deg of lat	0 to 90	0	Latitude of site (needed only if stability is to be computed by NAFCOM
	26-35	F5.0	TUNFAC	--	0.1 to 3	1	Tuning factor
	31-35	F5.0	ZCONST	m	3 to 10	10 (3)	Initial vertical diffusion
8	1-2	I2	IC	--	8	8	Card type number
	3-5	I3	L	--	1 to 200	151	link number on which count occurs (1 ≤ L ≤ NLINK)
	6-10	F5.0	COUNT(1,L)	veh	≥0	775	Count going straight from link L through the intersection during time period
	11-15	F5.0	COUNT(2,L)	veh	≥0	88	Count going right from link L
	16-20	F5.0	COUNT(3,L)	veh	≥0	107	Count going left from link L
	21-25	I5	L2	--	1 to 200	152	Link number on which count occurs
	26-30	F5.0	COUNT(1,L2)	veh	≥0	1064	Count going straight from link L2
	31-35	F5.0	COUNT(2,L2)	veh	≥0	0	Count going right from link L2
	36-40	F5.0	COUNT(3,L2)	veh	≥0	0	Count going left from link L2
	41-45	I5	L3	--	1 to 200	153	Link number on which count occurs
	46-50	F5.0	COUNT(1,L3)	veh	≥0	457	Count going straight from link L3
	51-55	F5.0	COUNT(2,L3)	veh	≥0	147	Count going right from link L3
	56-60	F5.0	COUNT(3,L3)	veh	≥0	170	Count going left from link L3
	61-65	I5	L4	--	1 to 200	154	Link number on which count occurs
	66-70	F5.0	COUNT(1,L4)	veh	≥0	429	Count going straight from link L4
	71-75	F5.0	COUNT(2,L4)	veh	≥0	0	Count going right from link L4
	76-80	F5.0	COUNT(3,L4)	veh	≥0	0	Count going left from link L4

Table D-3 (Concluded)

Table D-3 (Concluded)

Card	Column	Format	Symbol	Units	Value Limits	Typical Value (default value in parentheses)	Description
9	1-2	I2	IC	--	9	9	Card type number
	3-12	F10.5	XO(I)	ft	>0	2983.75	x-coordinate of receptor location
	13-22	F10.5	YO(I)	ft	>0	3774.25	y-coordinate of receptor location
10	1-2	I2	IC	--	10	10	Card type number
	3-10	F8.2	THETA(I)	deg from N	0 to 360	101	Wind direction
	11-18	F8.2	WS(I)	knots	≥1.94	3.89	Wind speed
	19-23 or 19-23	I5	ISTAB(I) or ICLD(I)	--	1 to 5	4	Stability class or
		I5		tenths	0 to 10	--	Cloud cover

*May not be 0 on first iteration of program.